Access-To-Egress: Factors Influencing Evacuations Through A Type-III Exit

G. A. 'Mac' McLean, Ph.D.

Protection and Survival Laboratory

Study Rationale

- Study was sponsored by FAA Transport Airplane Directorate in support of ARAC Harmonization of FAR 25.813(c).
- Study responded to NTSB Safety Study call for comparison of 13” versus 20” passageways leading to Type-III exits.
- Study also responded to NTSB Safety Study call for “realistic” evacuation research methodologies.

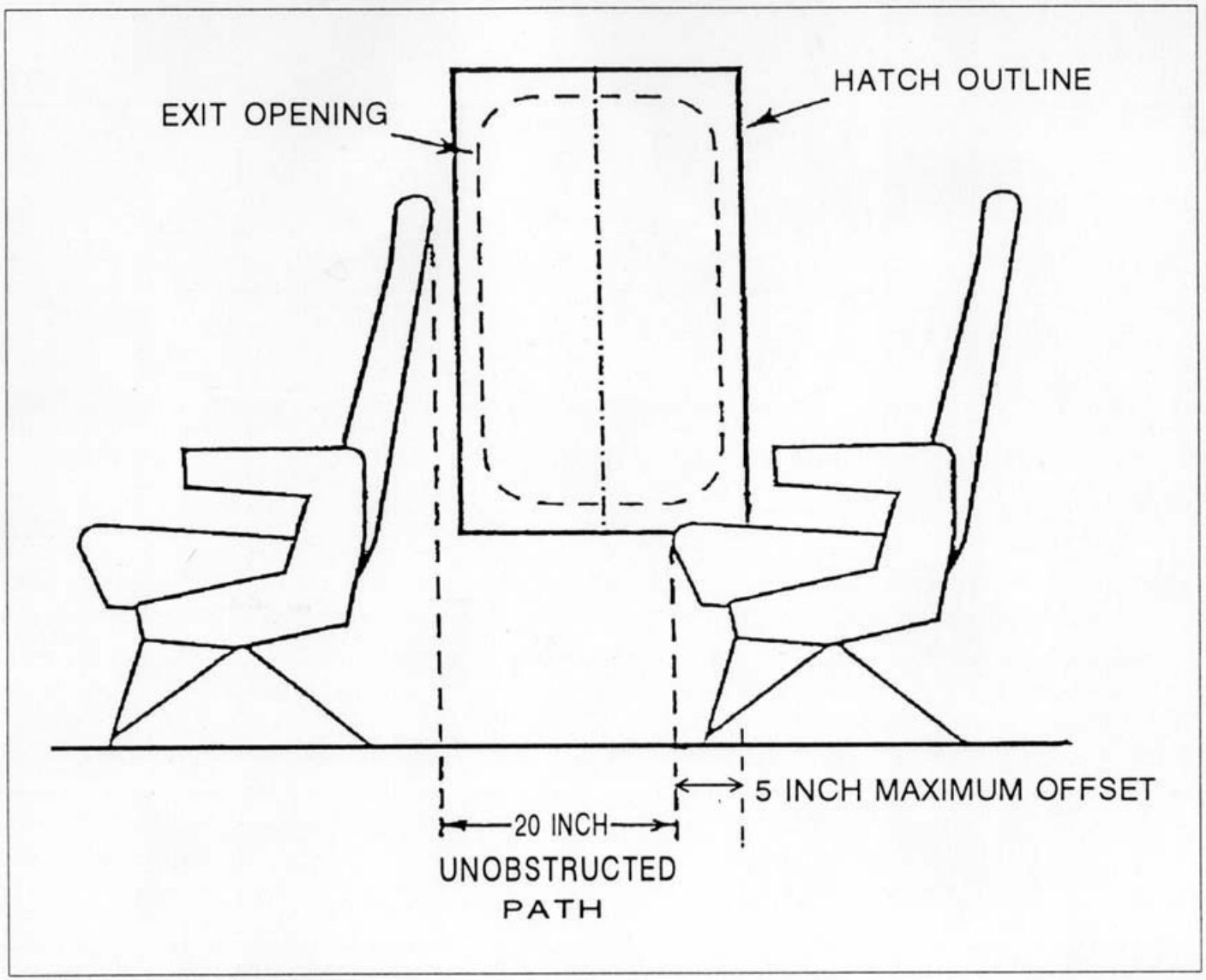
Study Highlights

- Largest evacuation study ever conducted.
- 2,544 subjects participated in 48 “naïve” evacuations.
- 192 of those “naïve” subjects opened the exit.
- Data collection required 13 weeks - often working 6 days/week.
- 25 CAMI and 14 contractor staff directly conducted the study.
- Over 20 additional CAMI personnel supported the study.
- International coordination and review was provided by UK Cranfield University research staff.

Research Design Factors

- **Between (naïve) - subjects factorial design.**
- **Passageway Configuration x Hatch Location x Subject Group Density x Subject Motivation**
- **Passenger (different for each trial) seated at the Type-III exit removed and disposed of the exit plug.**
- **Same combination of conditions were used repeatedly for 4 trials per subject group to allow further study of motivation and practice effects..**

FIGURE 1. CONFIGURATION "A"



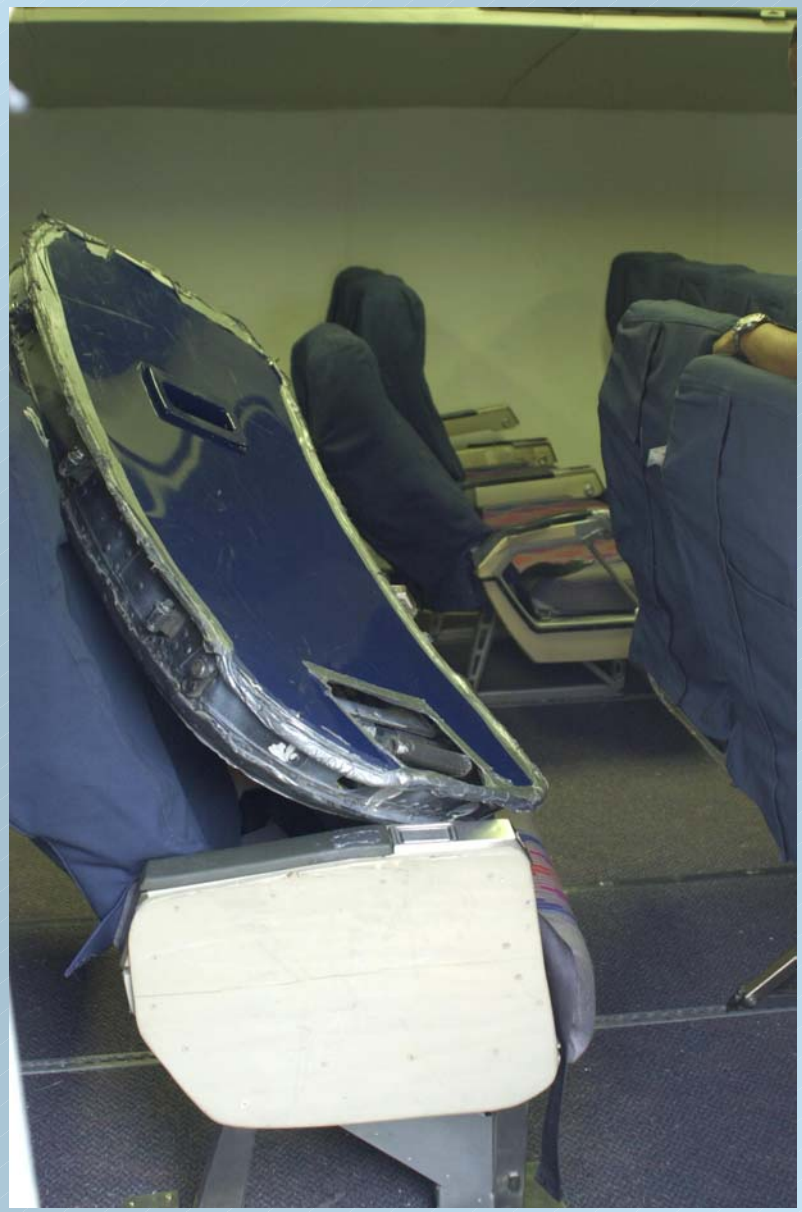
Passageway Configuration

- 6” dual passageways with outboard seat removed
- 10” passageway with 14” aft seat encroachment
- 13” passageway with 10” aft seat encroachment
- 20” passageway with 5” aft seat encroachment

Hatch Location

- ***Inside*** - The subject opening the exit was shown via briefing card, that after opening the exit, to place the hatch on the seat assembly where s/he had been sitting and then evacuate through the exit.
- ***Outside*** - The subject opening the exit was shown via briefing card, that after opening the exit, to place the hatch outside the airplane and then evacuate through the exit.

Inside Hatch Location



Outside Hatch Location

Hatch Weight

The weight of the hatch was set at 45 lbs.

for all trials.

Subject Group Density

- There were either 30, 50, or 70 subjects per group, depending on the experimental condition.
- Higher subject group density had previously been shown to exponentially impede egress, relative to lesser densities, suggesting that density could be used as a discriminant for deciding the size of airplanes to which the harmonized rules should be applied.

Subject Motivation

The Low-Motivation groups were instructed that the airplane had “crashed” and was “on fire” and that to stay alive they had to hurry to get out. Flight attendants commanded the evacuations from the front and rear of the cabin.

Low Motivation Condition

Subject Motivation

The High-Motivation groups were also told the airplane had “crashed” and was “on fire” and that they had to hurry out to stay alive. Double pay was offered to individuals in the group who got out of the aircraft ahead of others, evacuation performance being averaged over all 4 evacuation trials for each group. Flight attendants commanded the evacuations from the front and rear of the cabin.

High Motivation Condition

Design Factors

Exit Plug:		Inside				Outside			
Passageway:		**6”**	**10”**	**13”**	**20”**	**6”**	**10”**	**13”**	**20”**
Density	***Motive***								
Low	**Low**	Gp1	Gp 2	Gp 3	Gp 4	Gp 5	Gp 6	Gp 7	Gp 8
(30)	**High**	Gp 9	Gp 10	Gp 11	Gp 12	Gp 13	Gp 14	Gp 15	Gp 16
Medium	**Low**	Gp 17	Gp 18	Gp 19	Gp 20	Gp 21	Gp 22	Gp 23	Gp 24
(50)	**High**	Gp 25	Gp 26	Gp 27	Gp 28	Gp 29	Gp 30	Gp 31	Gp 32
High	**Low**	Gp 33	Gp 34	Gp 35	Gp 36	Gp 37	Gp 38	Gp 39	Gp 40
(70)	**High**	Gp 41	Gp 42	Gp 43	Gp 44	Gp 45	Gp 46	Gp 47	Gp 48

**** 6” passageway is OBR configuration***

Flight Attendant Participation

Two uniformed flight attendants were seated in the jump-seats in the fore and aft of the cabin. At the start signal, the F/As commanded the evacuation from the front and rear of the crowd, shouting evacuation commands as if coming from their primary exits. F/As were not allowed to “touch” subjects in any way. Provision of F/As was intended to keep subjects “on task” as in an actual emergency evacuation.

Flight Attendants

Subject Briefings

- Initial Subject Briefing
- Informed Consent
- Subject Screening
- Hatch Handler Briefing
- Facility Orientation
- Safety Briefing
- Motivation Briefing
- Pre-Trial Briefing

Initial Subject Briefing

Welcome... Today you will be participating in a research project… The area of concern for today's trials is emergency aircraft evacuations, or in other words, getting out of the aircraft rapidly. Emergency evacuations are performed on real aircraft when an accident or malfunction occurs which demands that passengers leave the aircraft as quickly as possible for their own safety... In today's experiment, you will be required to sit in an airplane seat in our aircraft mock-up, then perform a simulated emergency evacuation. You may be called upon to remove an escape hatch that weighs 45 pounds. You will be required to leave your seat and travel to the exit for escape. The exit is an opening 38 inches high by 20 inches wide. The sill of the exit is 19 inches above the floor, and 27 inches above the ground outside the aircraft… Although no real danger will exist in our trial today, we want you to understand the unlikely hazards associated with emergency evacuations may include, but are not limited to cuts, bruises, and broken bones. These injuries can occur from bumping into seats or other cabin items and from slipping, tripping, or falling. Still, we ask that you act as if this were a real emergency situation and perform as rapidly as possible in an effort to collect realistic data…Any questions?

Informed Consent Briefing

I understand that the research today concerns escape from airplanes through a Type III emergency exit. These exits, located in the overwing area, are used on aircraft to allow passengers to get out of the cabin when an accident or malfunction occurs. This study will help identify methods of using the exits in a more beneficial way. I understand that this research will be conducted using the CAMI evacuation simulator. I will be seated inside the simulator, with my seatbelt fastened, then, when the start signal is given, I will unbuckle my seatbelt, and move quickly to, and through the exit to the outside of the simulator. After exiting the simulator, I must move out of the way of others coming out behind me. It is important to always follow the directions given by the research team and flight attendants. I understand that there are possible injuries that I could receive from my participation. I have had opportunities to ask questions and all my questions have been answered to my satisfaction. I have no physical disabilities that would prevent me from being able to evacuate an aircraft cabin, nor any illnesses, such as heart disease, or other conditions, such as pregnancy, that restrict my ability to exercise or make this activity additionally hazardous. I understand that I must not trample or knock down any other person, or use excessive physical pushing and shoving while maneuvering to the exit.

Subject Screening

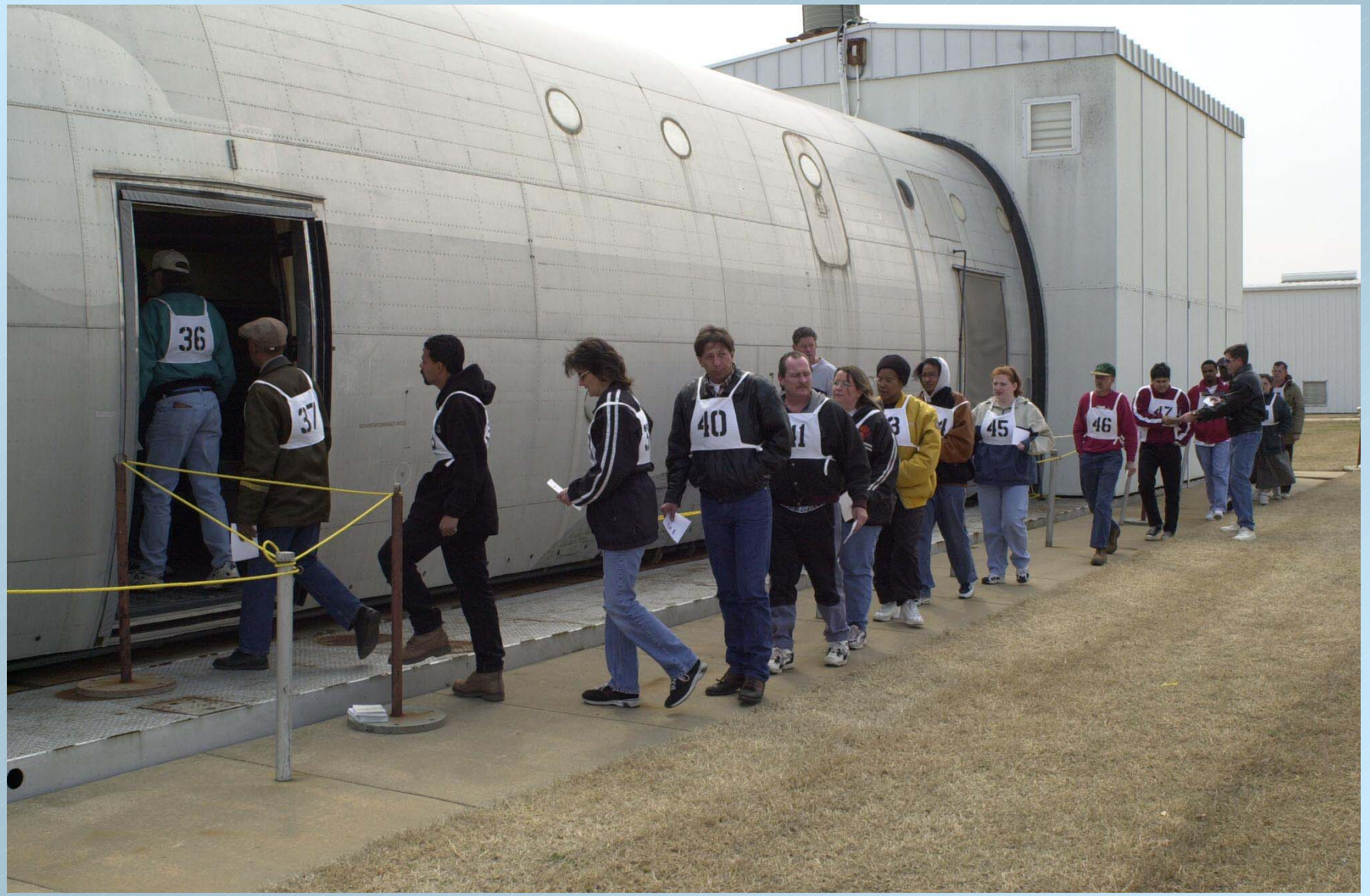
Subject Screening

Hatch Handler Briefings

Hatch Handler Check

Facility Orientation

Boarding



Simulator Safety Briefing

The experiment we are conducting today is very important to the future of aviation safety. To insure that you get all the information you need, please remain quiet and listen at all times to the instructions of the research team.

Emergency aircraft evacuations are conducted when extreme situations such as a crash with fire develop. They requires passengers to get out of their seats, hurry to the exit, and get outside the exit as fast as possible. Although you must move ***very*** fast, do not trample, knock down, or use excessive physical force on the other passengers during these evacuations. Even though the tests only ***simulate*** real emergencies, ***such as aircraft fires***, the potential risks of injury are similar to those you could experience in a real evacuation.

While we have taken every foreseeable precaution to insure your personal safety, occasionally the unexpected happens. If an unsafe condition occurs, a member of the research team will stop the evacuation by sounding this alarm (sound bell). If you hear the alarm at any time during the evacuation, immediately stop moving, stay where you are, and wait for further instructions.

High Motivation Briefing

Twenty-five percent of you will receive double the regular pay for your participation today. Success in being one of those to get this bonus pay depends on getting out of the airplane mock-up ahead of as many other people as possible. In order to win the bonus, you must be in the fastest ¼ of evacuees to get out the exit, averaged across all four evacuations. This means you might be the last person out of the mock-up in one of the evacuations, but still be able to win the bonus if you improve your relative position in the other evacuations. **Don't give up.** You will be seated in a different location for each evacuation - sometimes close to the exit and sometimes farther away. The seating rotation is balanced so that when all the evacuations are completed, everyone will have had an equal chance of winning the bonus. Questions?

Subject Briefings

Pre-Trial Briefing

Please make sure your seat belt is fastened securely around you. To fasten your seat belt, insert the metal fitting into the buckle (demonstrate). Tighten the belt by pulling on the loose end of the strap. To release the belt, lift up on the buckle flap. In a short time the start buzzer will sound to signal the beginning of the evacuation. When you hear the buzzer, immediately unbuckle your seat belt, get up, and leave the aircraft through the exit as fast as you can. If you have any questions, please ask now (pause).

Remember – we are simulating a commercial airplane crash in which an intense fire has developed. To stay alive we must get out of here as fast as we can. **Hurry!**

Start The Evacuation

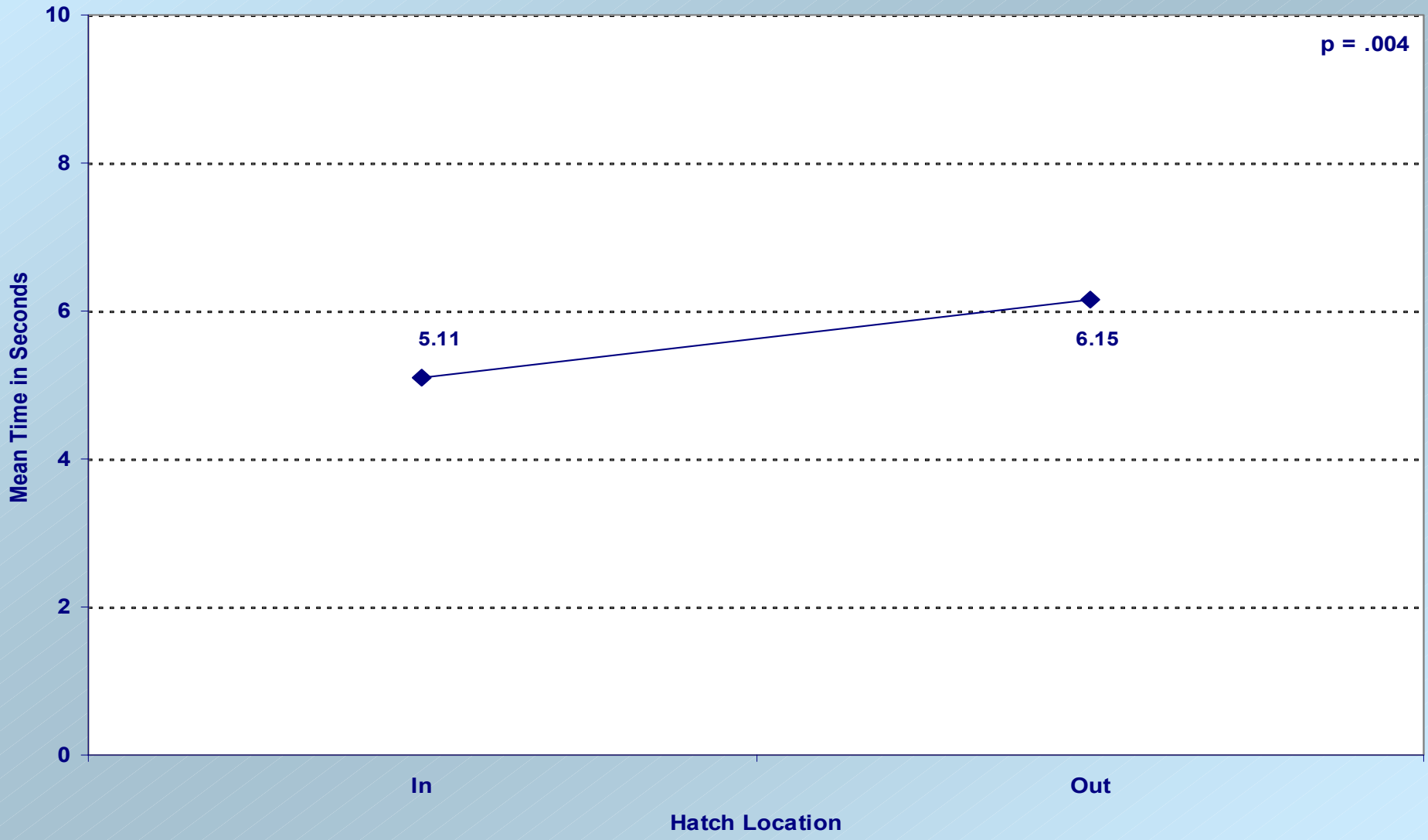
Data Acquisition & Archival

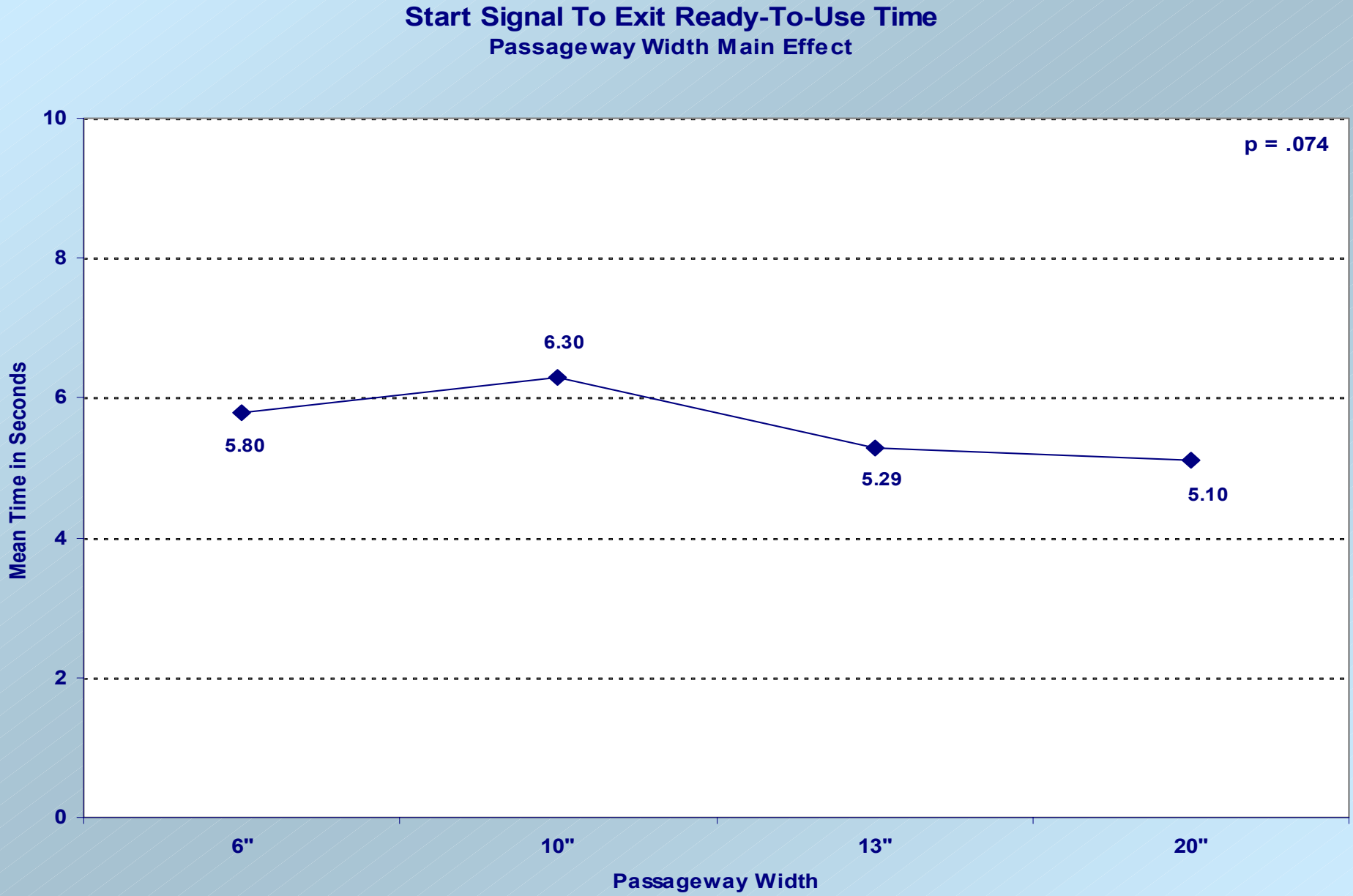
Experimental Findings

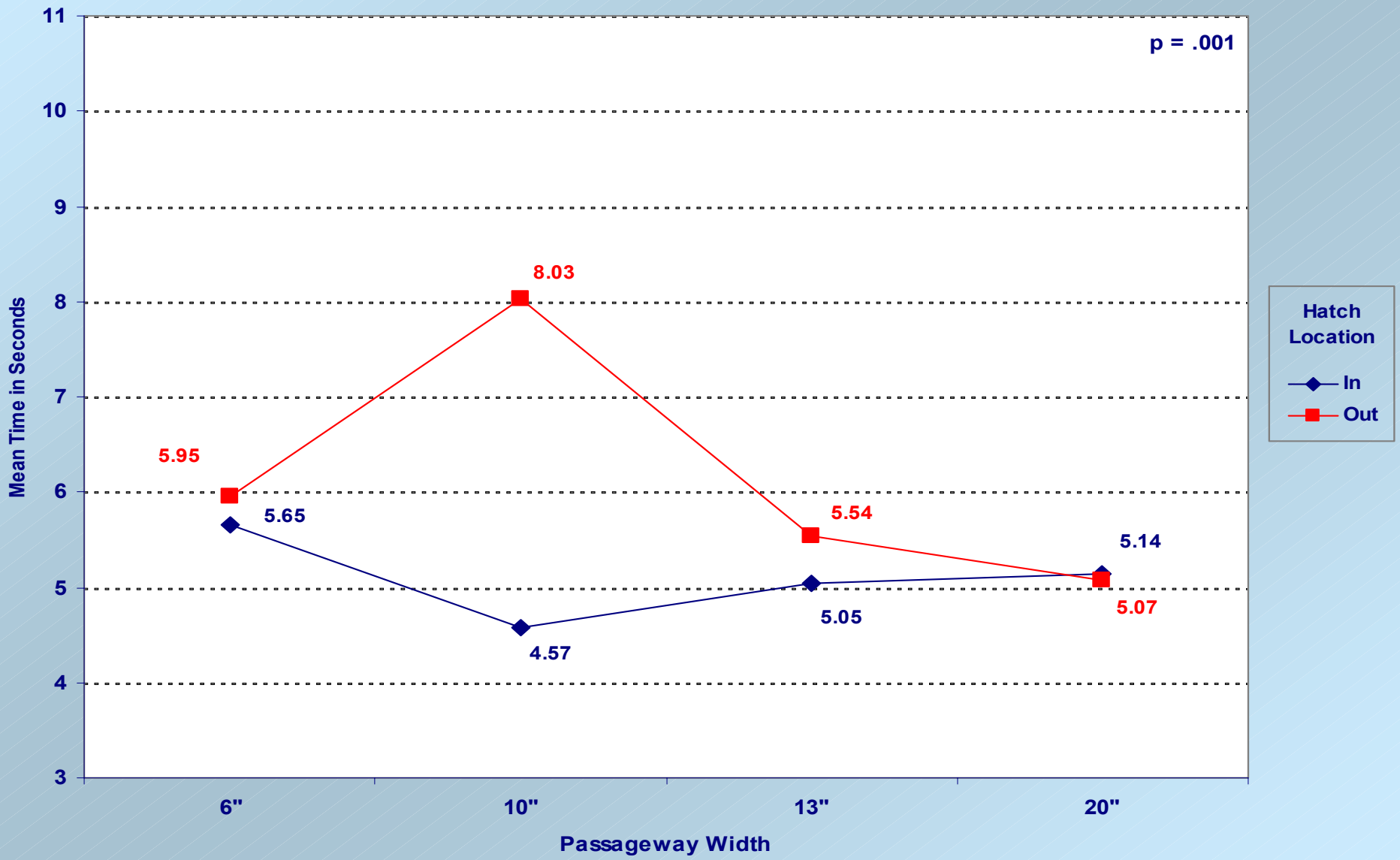
- **Hatch Effects**
  - **Ready-To-Use Time**
  - **First-Person-Out Time**
  - **Hatch-Handler-Out Time**
- **Evacuation Effects**
  - **Design Factors Effects On Flow Rate**
  - **Human Factors Effects On Flow Rate**

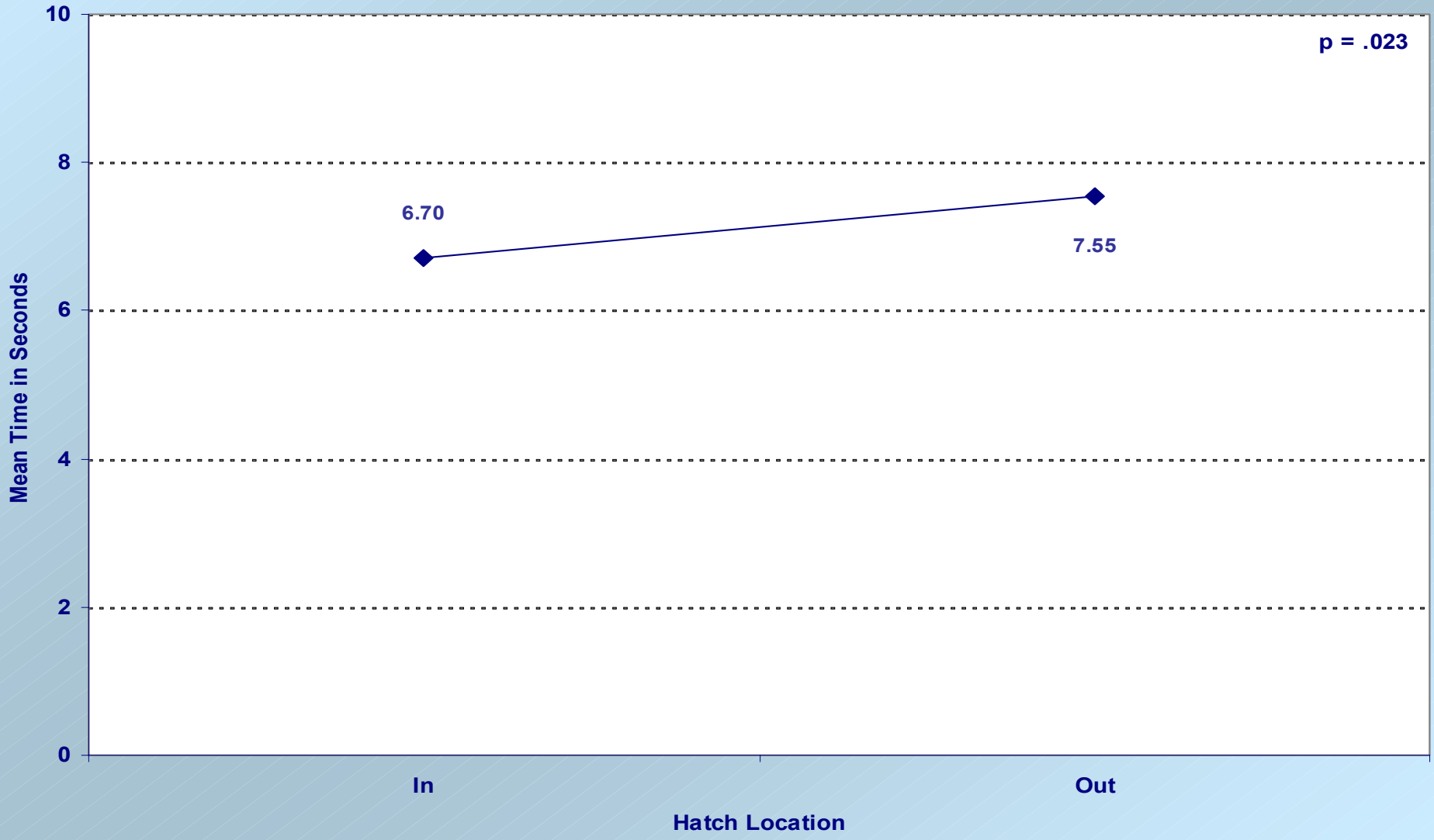
Hatch Effects

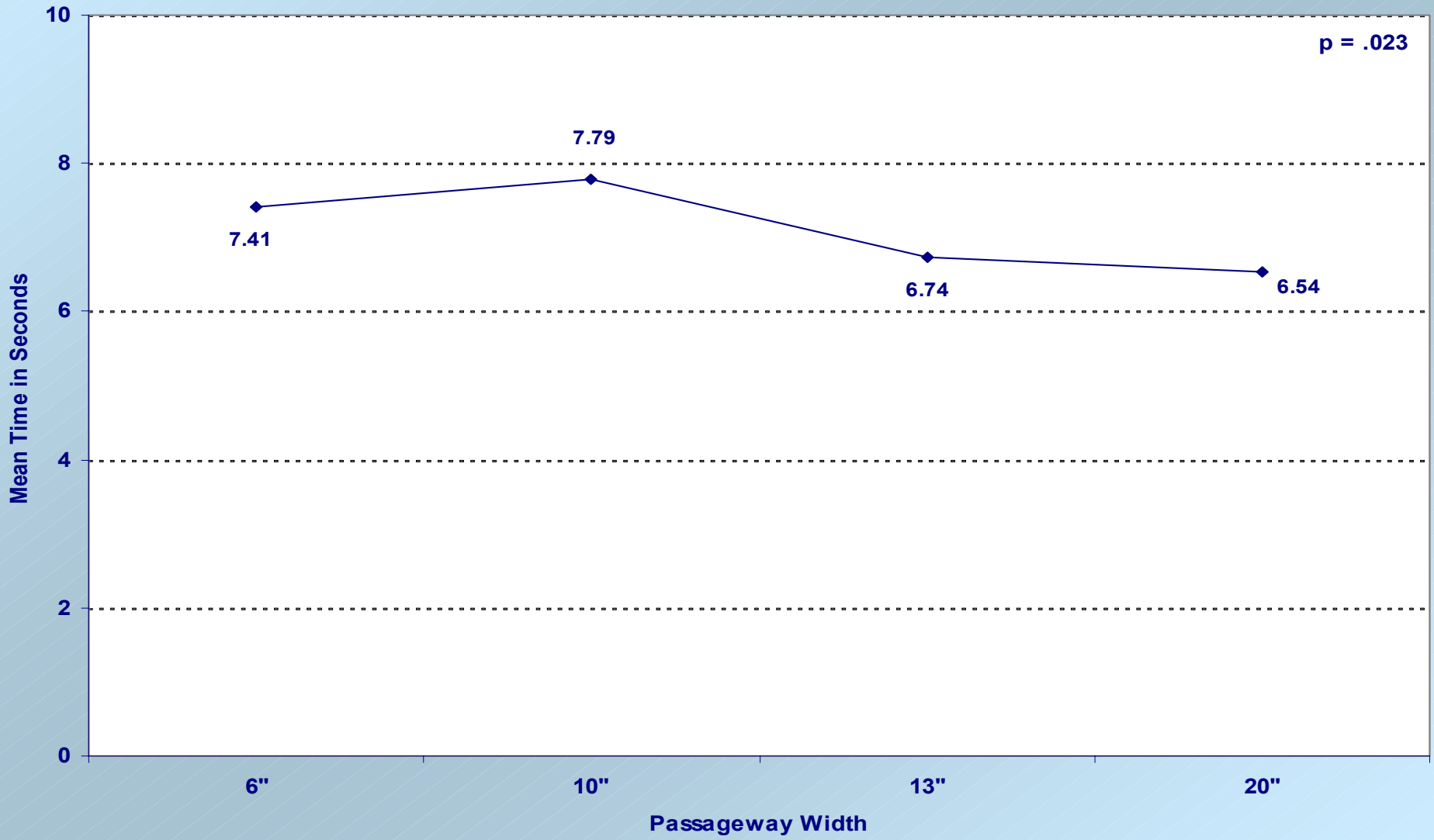
- Ready-to-Use Time
- First-Person-Out Time
- Hatch-Handler-Out Time

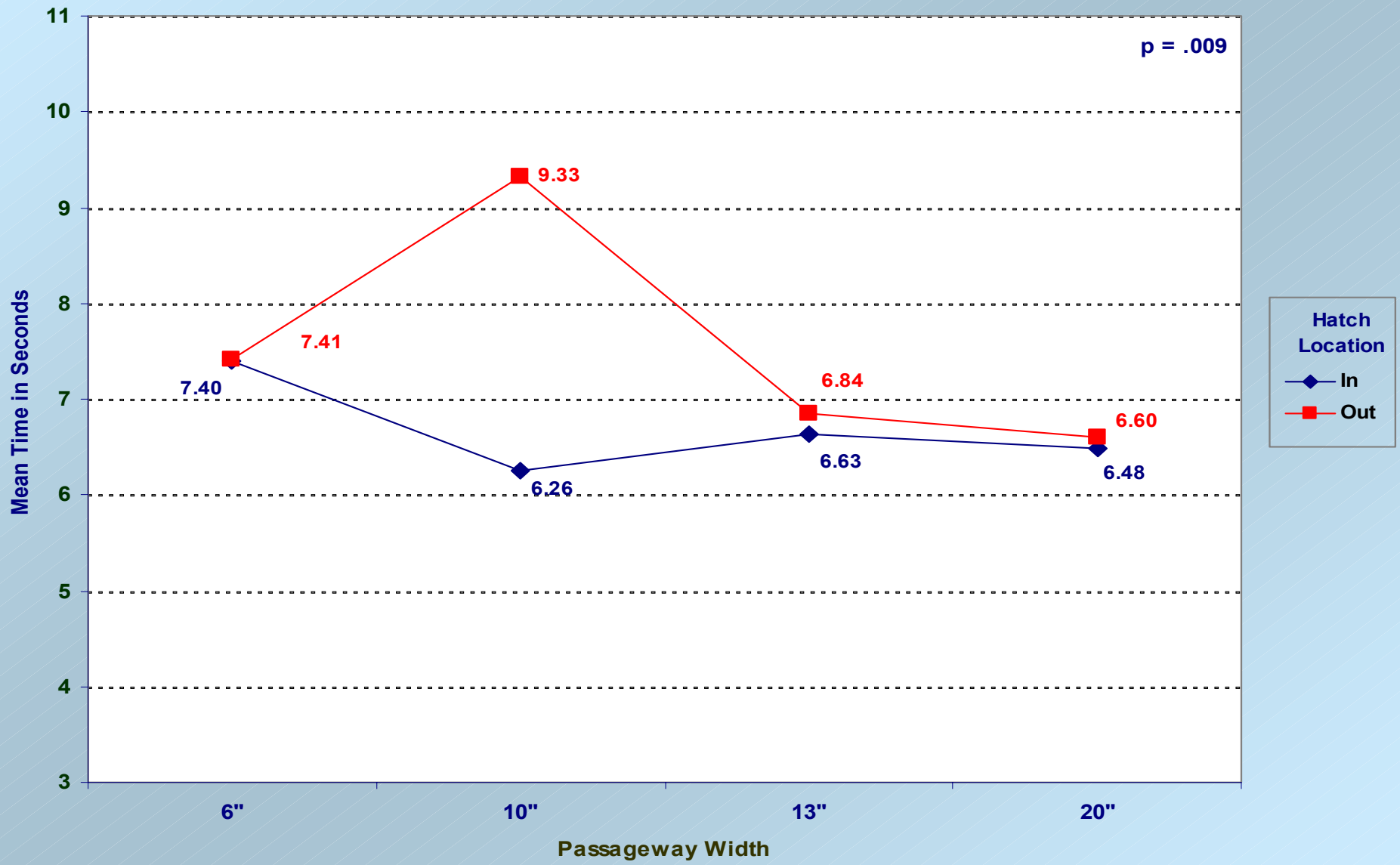

Start Signal To Exit Ready-To-Use Time
Hatch Location Main Effect
p = .004
Mean Time in Seconds
10
8
6
4
2
0
5.11
6.15
In
Out
Hatch Location

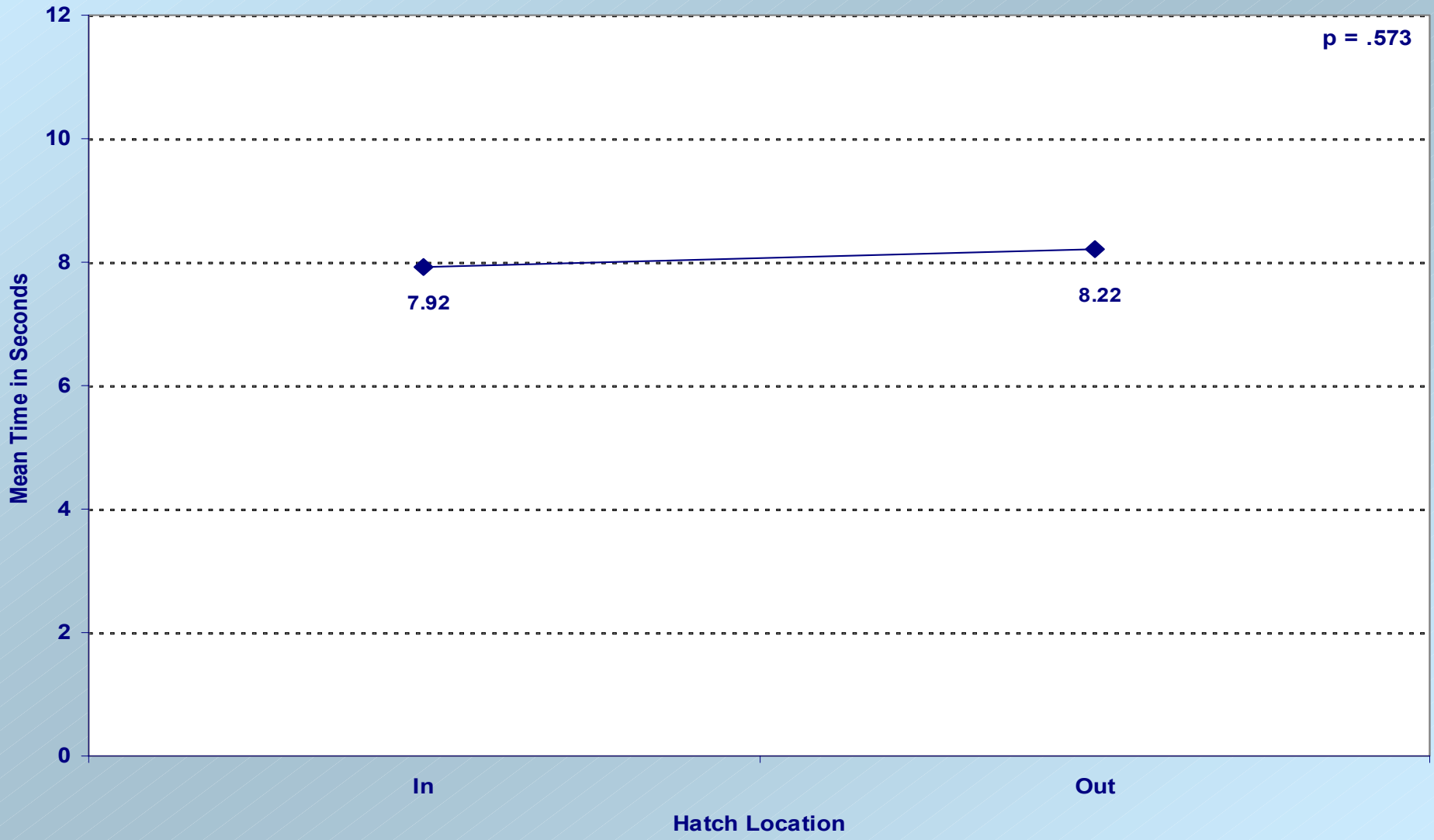

Start Signal To Exit Ready-To-Use Time
Passageway Width Main Effect
p = .074
Mean Time in Seconds
10
8
6
4
2
0
6.30
5.80
5.29
5.10
6"
10"
13"
20"
Passageway Width

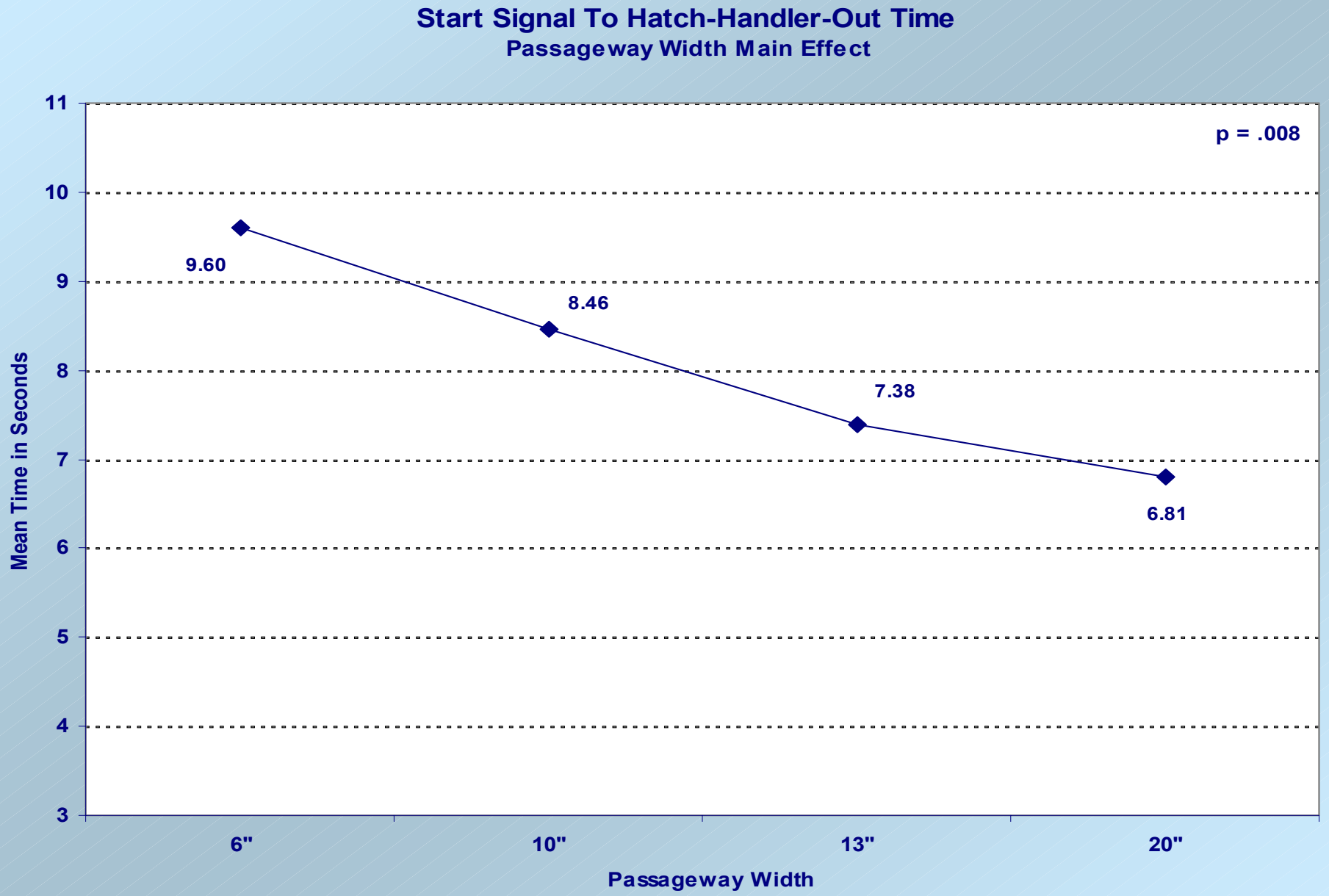

Start Signal To Exit Ready-To-Use Time
Passageway Width X Hatch Location Interaction
p = .001
Mean Time in Seconds
11
10
9
8
7
6
5
4
3
8.03
5.95
5.65
5.54
5.14
5.05
4.57
5.07
6"
10"
13"
20"
Passageway Width
Hatch Location
In
Out

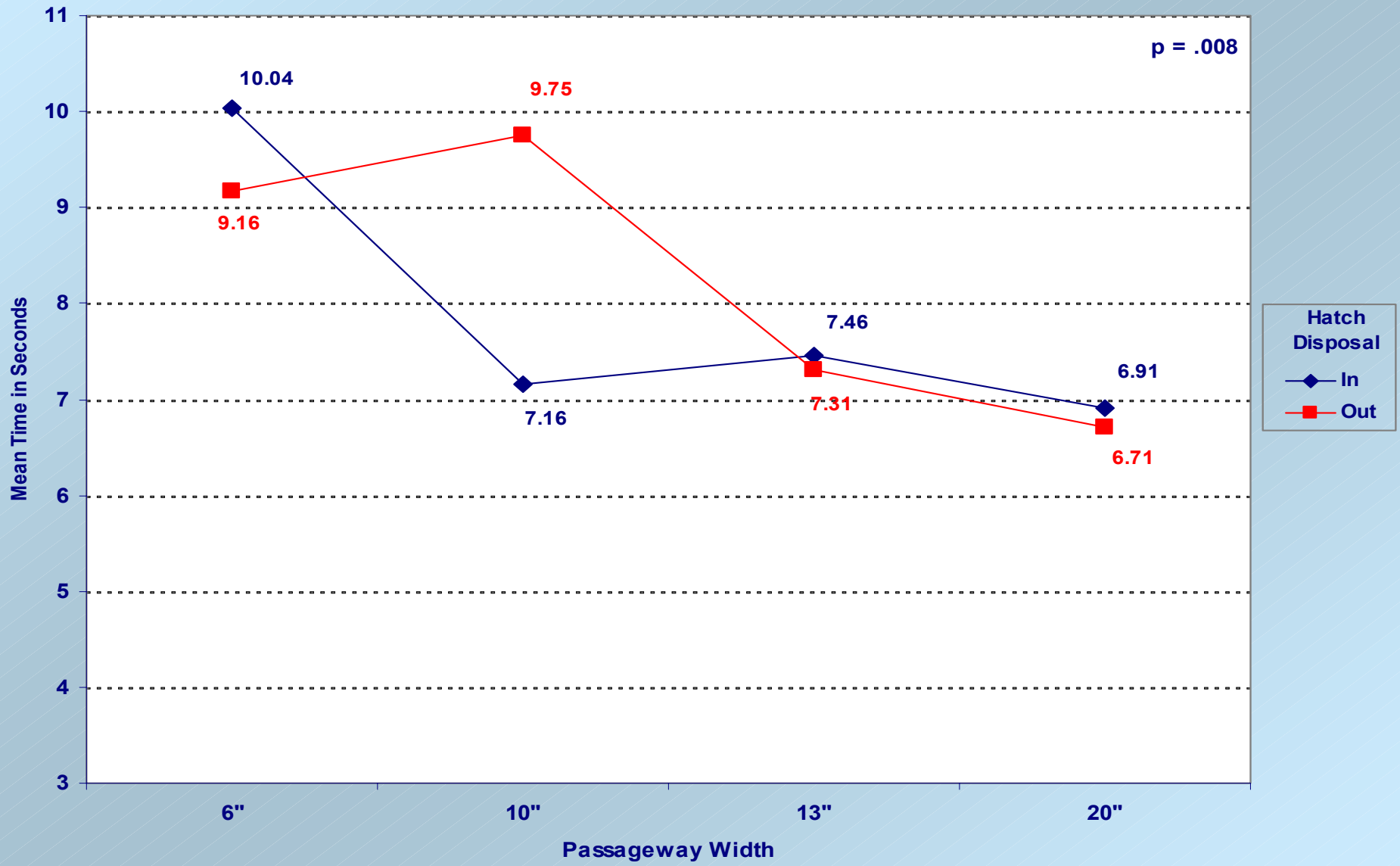

Start Signal To First-Passenger-Out Time
Hatch Location Main Effect
p = .023
10
8
6
4
2
0
Mean Time in Seconds
6.70
7.55
In
Out
Hatch Location


Start Signal To First-Passenger-Out Time
Passageway Width Main Effect
p = .023
Mean Time in Seconds
10
8
6
4
2
0
7.41
7.79
6.74
6.54
6"
10"
13"
20"
Passageway Width


Start Signal To First-Passenger-Out Time
Passageway Width X Hatch Location Interaction
p = .009
Mean Time in Seconds
11
10
9
8
7
6
5
4
3
9.33
7.41
7.40
6.84
6.60
6.63
6.48
6.26
6"
10"
13"
20"
Passageway Width
Hatch Location
In
Out


Start Signal To Hatch-Handler-Out Time
Hatch Location Main Effect
p = .573
12
10
8
6
4
2
0
Mean Time in Seconds
7.92
8.22
In
Out
Hatch Location


Start Signal To Hatch-Handler-Out Time
Passageway Width Main Effect
p = .008
Mean Time in Seconds
11
10
9
8
7
6
5
4
3
9.60
8.46
7.38
6.81
6"
10"
13"
20"
Passageway Width


Start Signal To Hatch-Handler-Out Time
Passageway Width X Hatch Disposal Interaction
p = .008
Mean Time in Seconds
11
10
9
8
7
6
5
4
3
10.04
9.75
9.16
7.46
6.91
7.16
7.31
6.71
6"
10"
13"
20"
Passageway Width
Hatch Disposal
In
Out

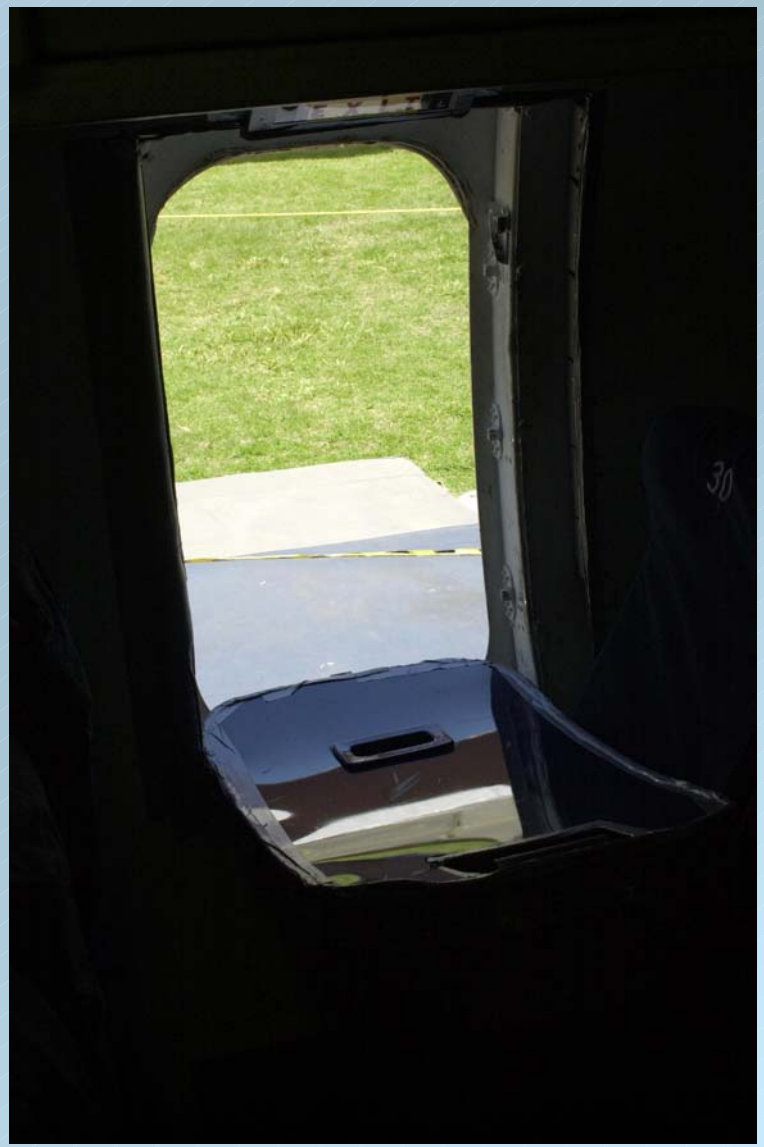
Conclusions

- Hatch preparation time is influenced little by passageway configuration - except for “outside” hatch disposal at the 10” configuration - which was dependent on ergonomic constraints.
- Hatch handler egress may be delayed because of hatch disposal activities and egress by other passengers.
- Subjects can and will comply with hatch removal and disposal instructions when they understand what is expected.
- Positive review of briefing cards by hatch handlers allowed them to understand the intended method of hatch removal/disposal.
- The results indicate that passengers can be more effective survivors if they are properly informed about emergency procedures.

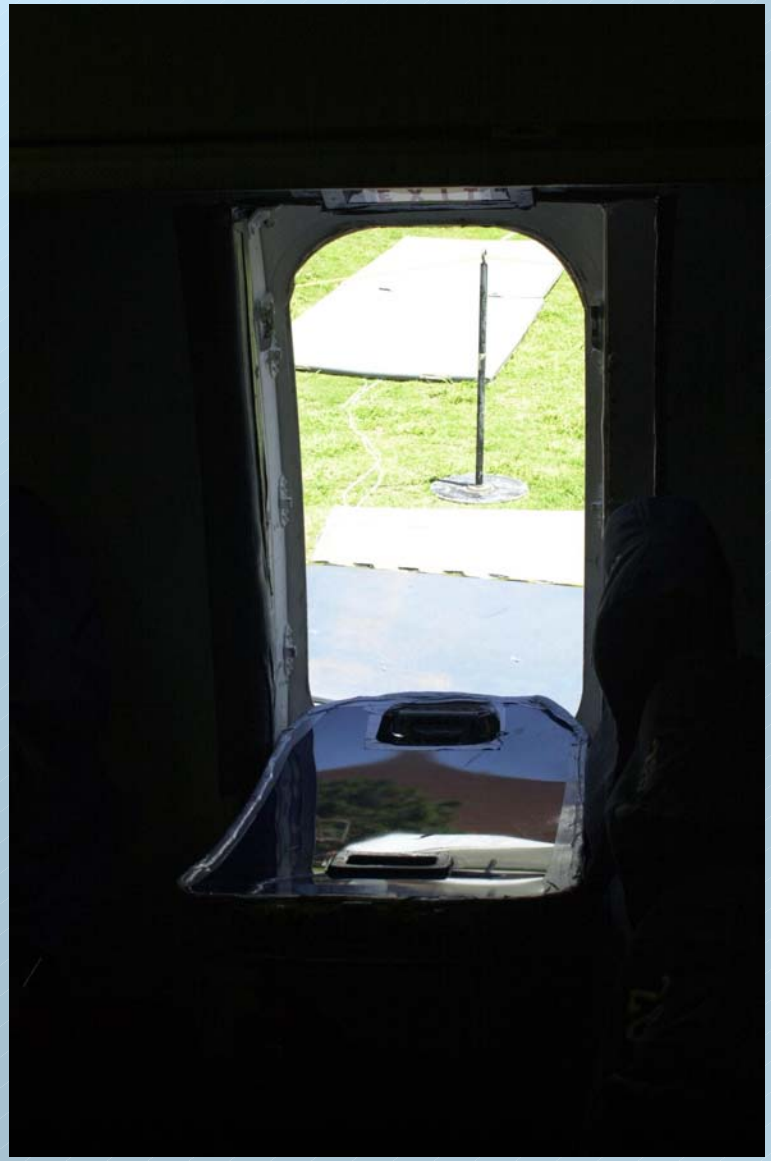
Hatch Disposal Outliers

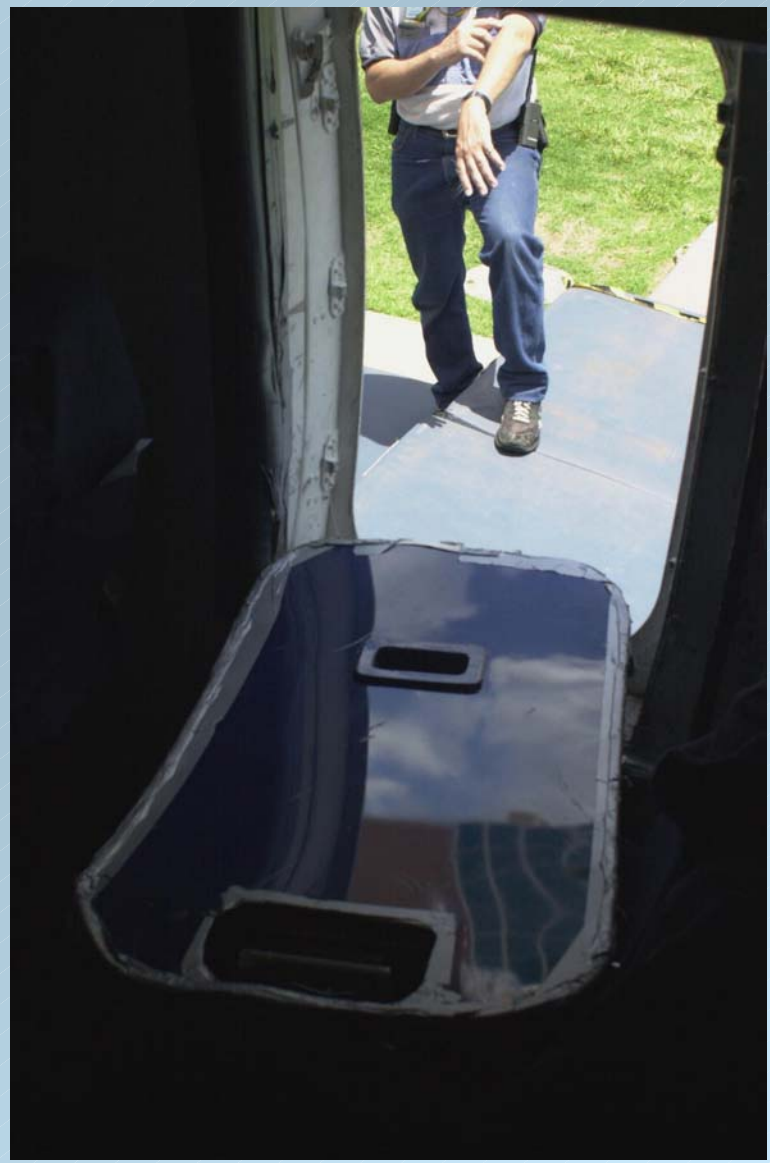
- On 4 Evacuation trials the hatch formed a “slide” out the exit
- On 4 evacuation trials the hatch ended up on the passageway floor
- On 3 evacuation trials the hatch ended up in a rear seat
- On 2 evacuation trials the hatch obstructed the exit
- On 1 evacuation trial the hatch ended up across the aisle
- On 1 evacuation trial the hatch ended up wedged between the outboard seat and the fuselage

Hatch Disposal Outliers



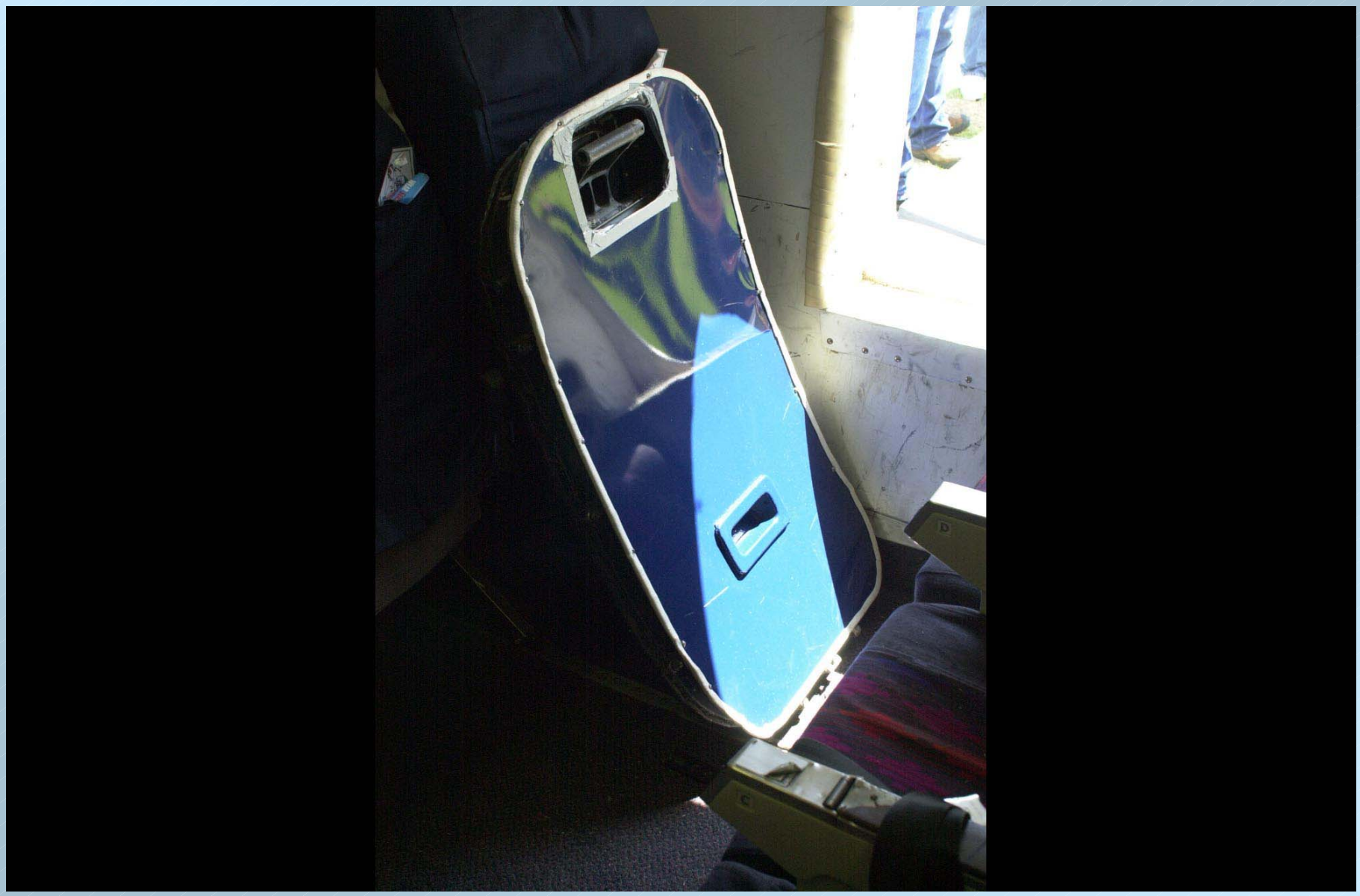
Hatch Disposal Outliers



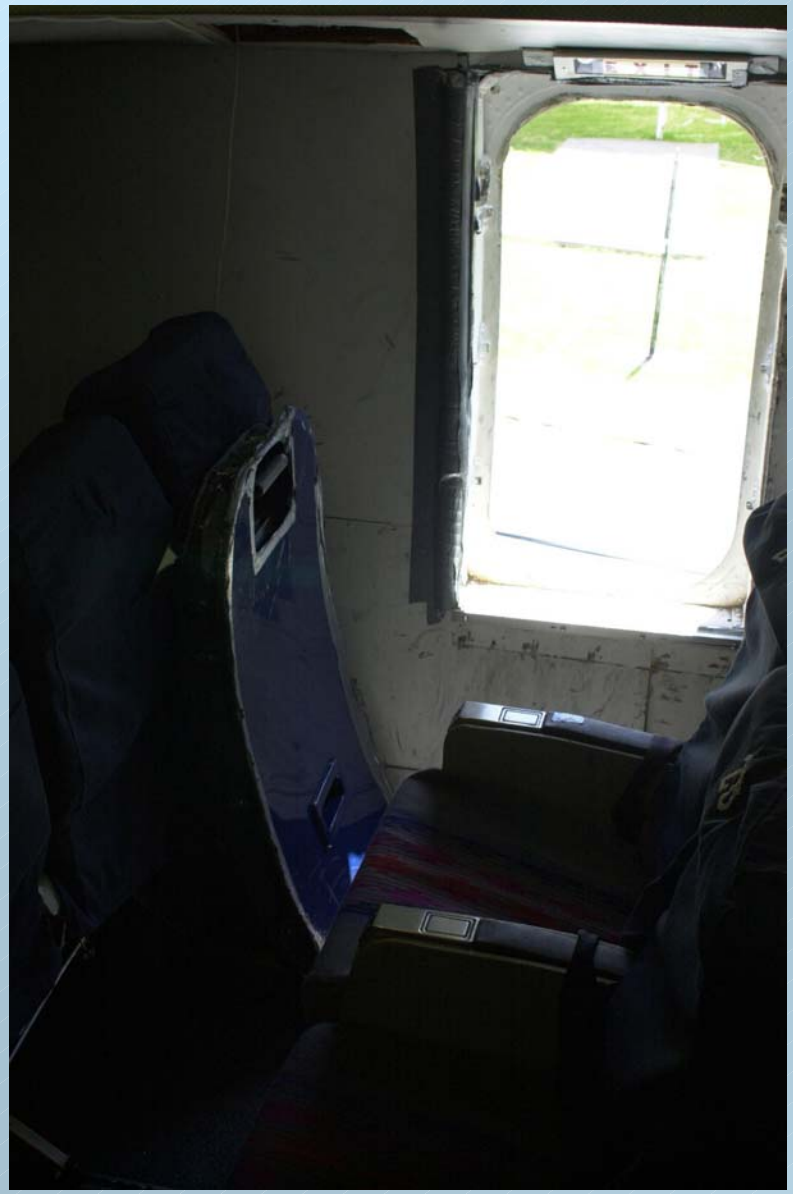


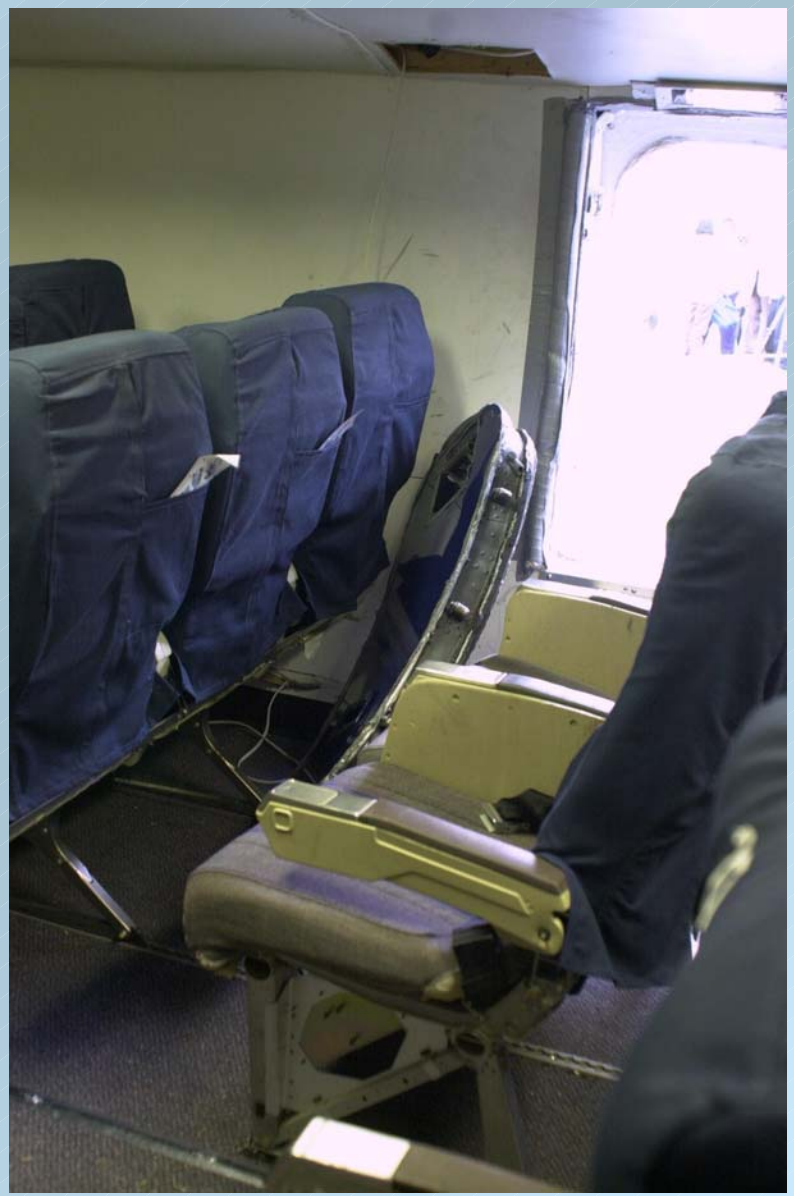
Hatch Disposal Outliers

Hatch Disposal Outliers

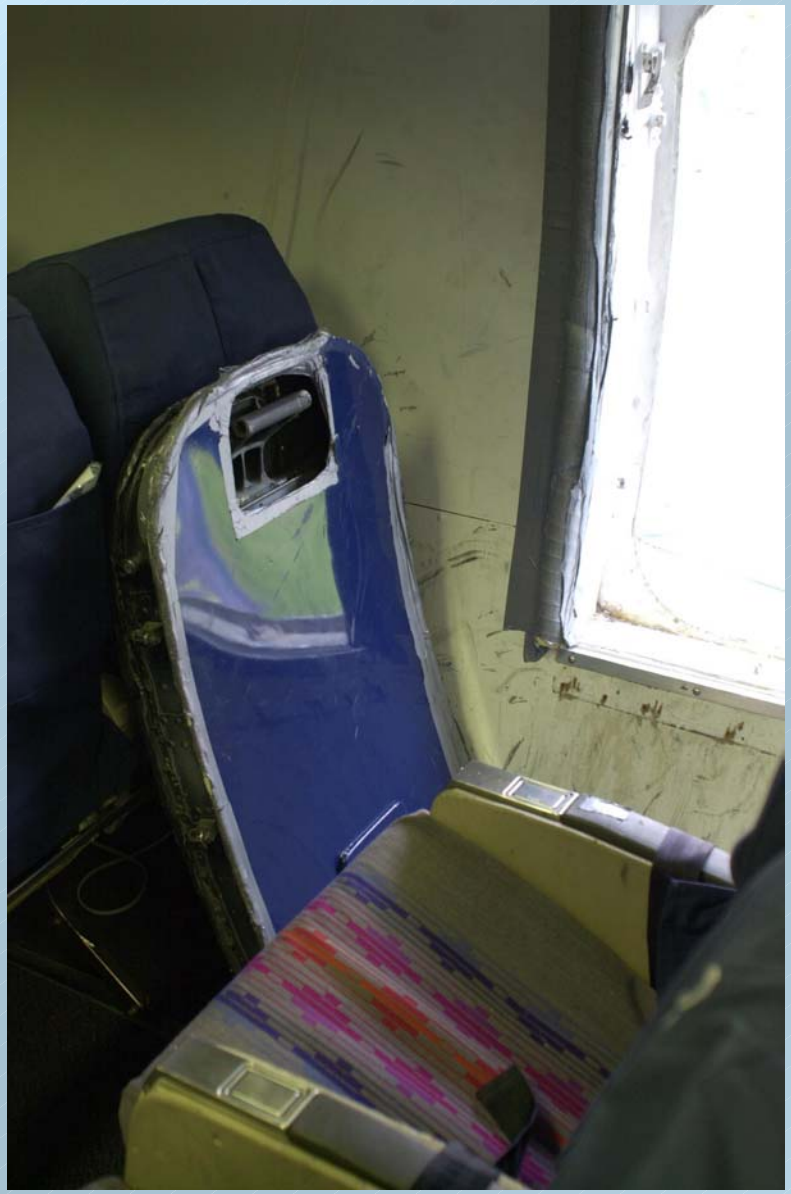


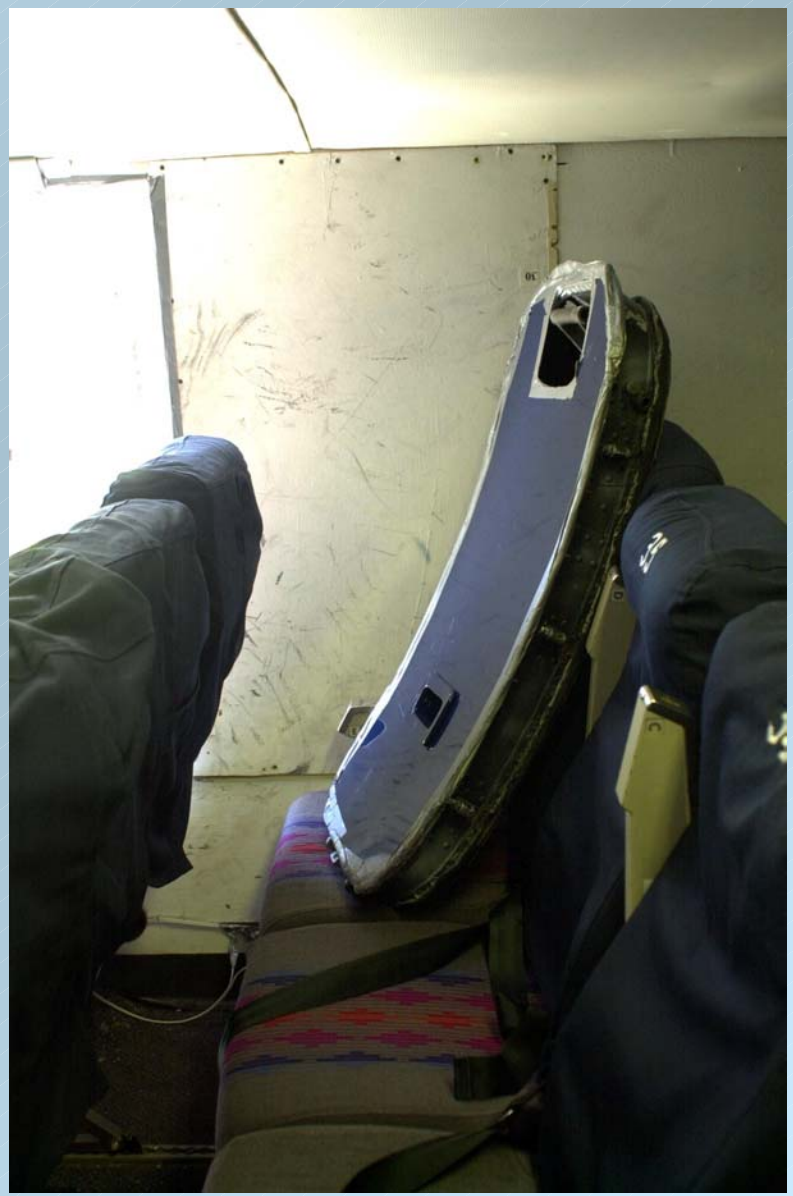
Hatch Disposal Outliers





Hatch Disposal Outliers





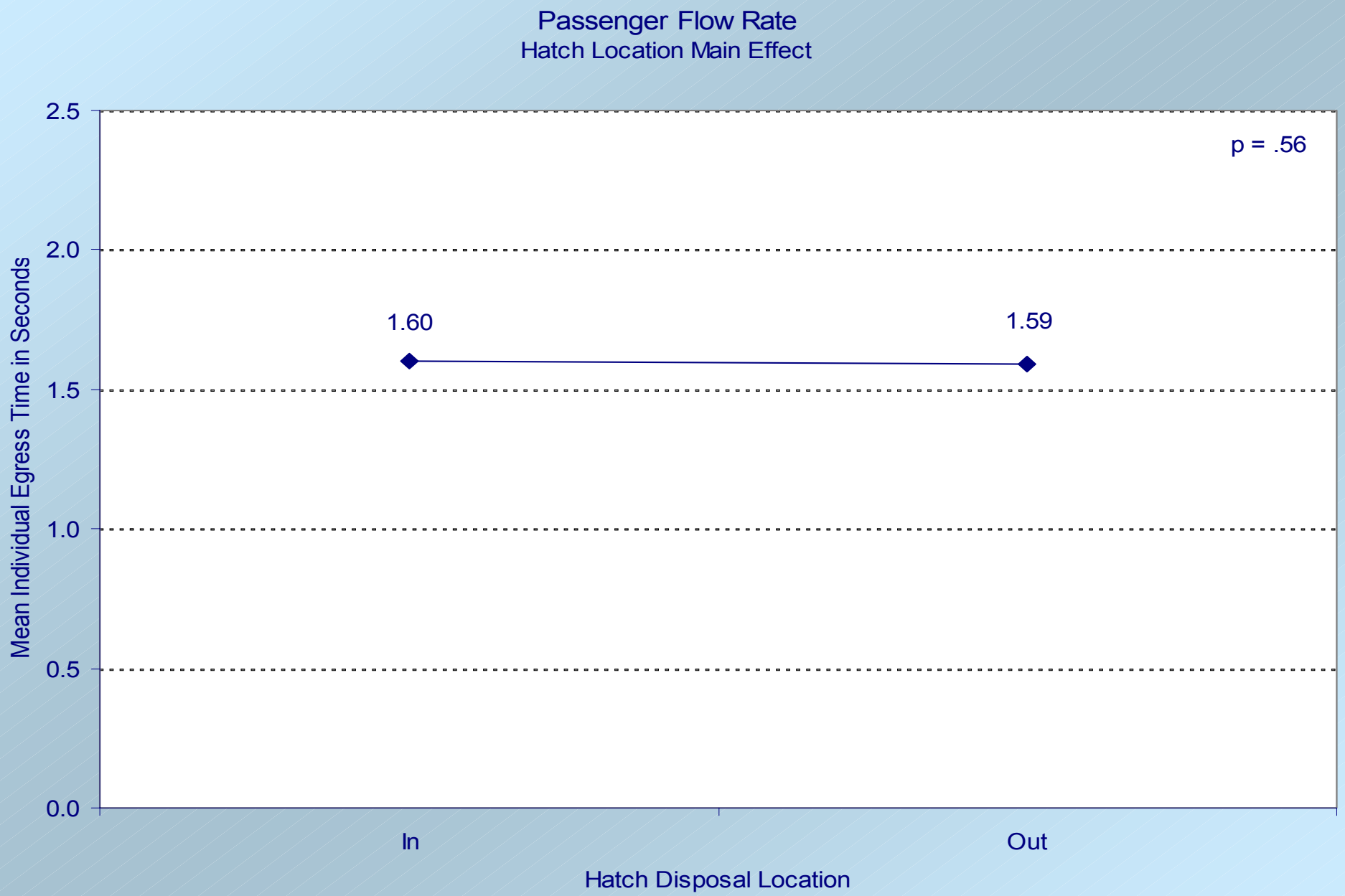
Hatch Disposal Outliers

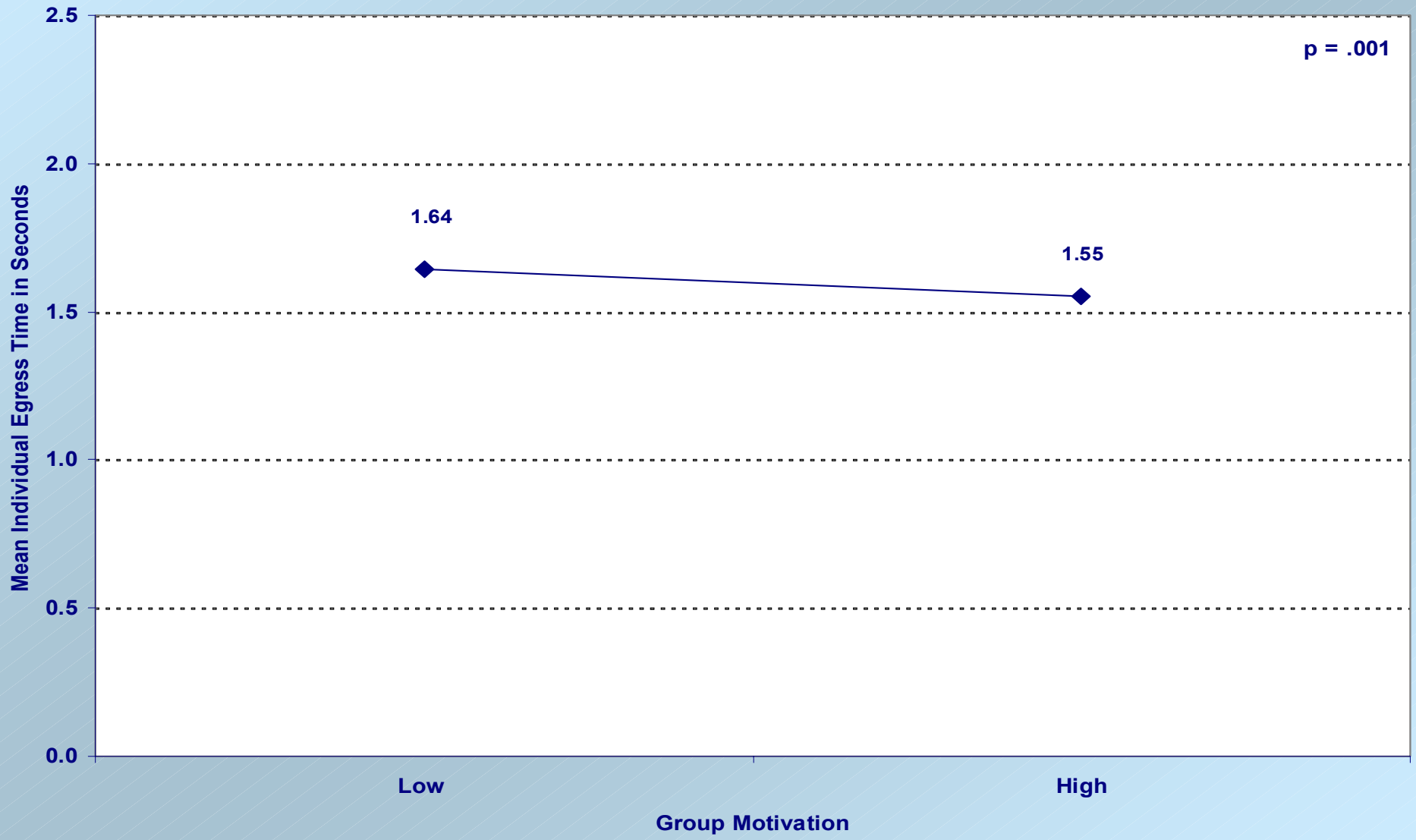
Hatch Disposal Outliers

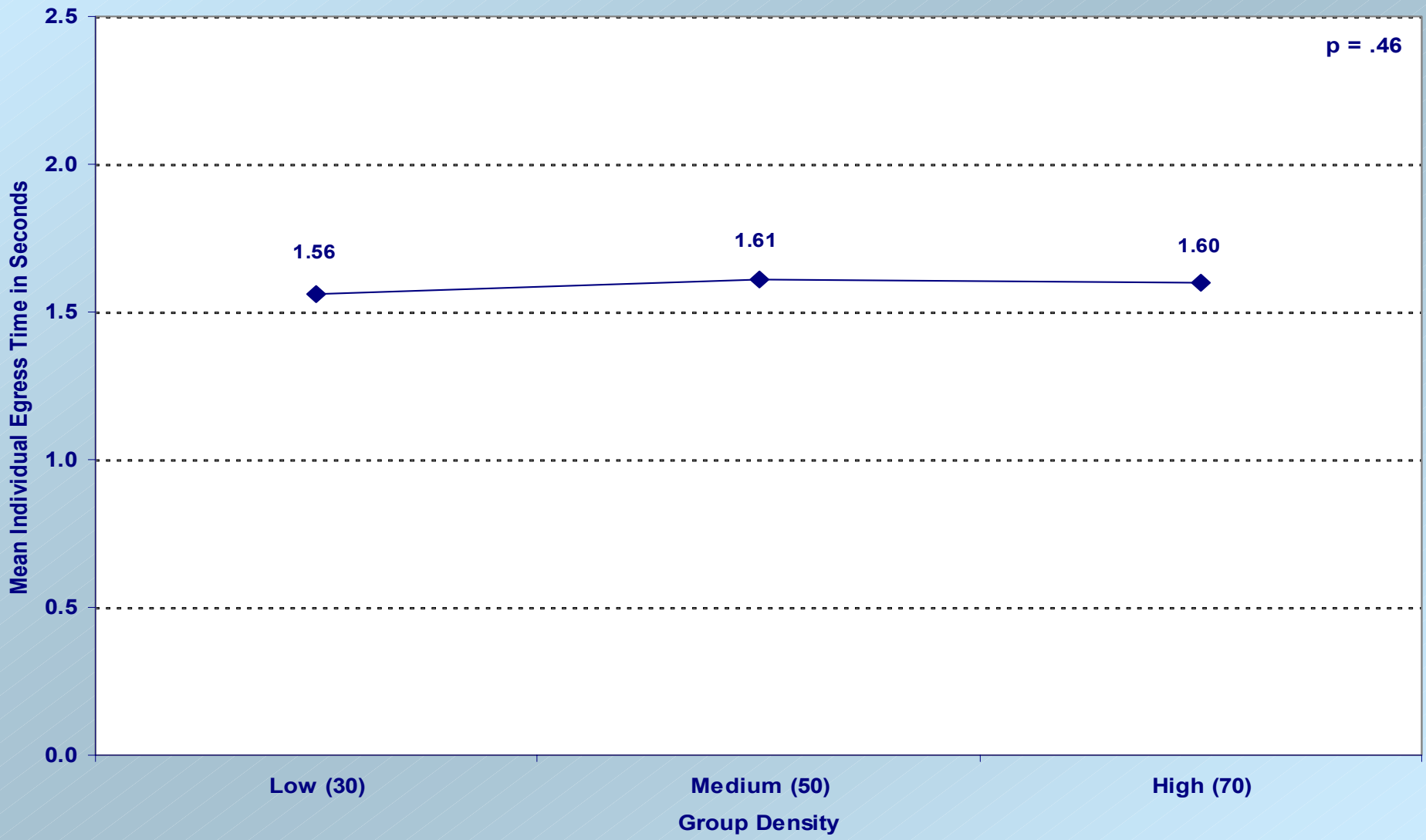
Hatch Disposal Outliers

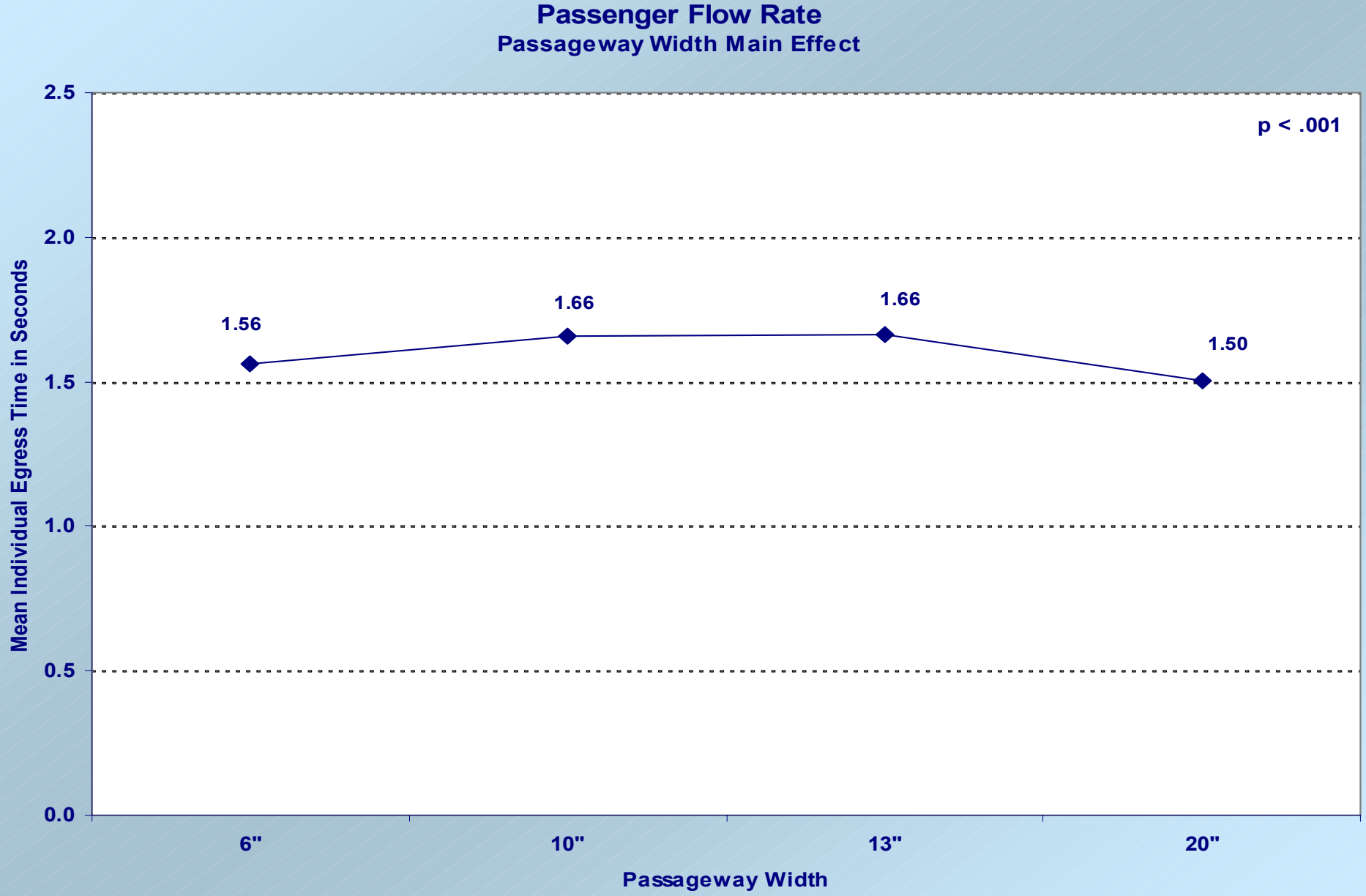
Evacuation Effects

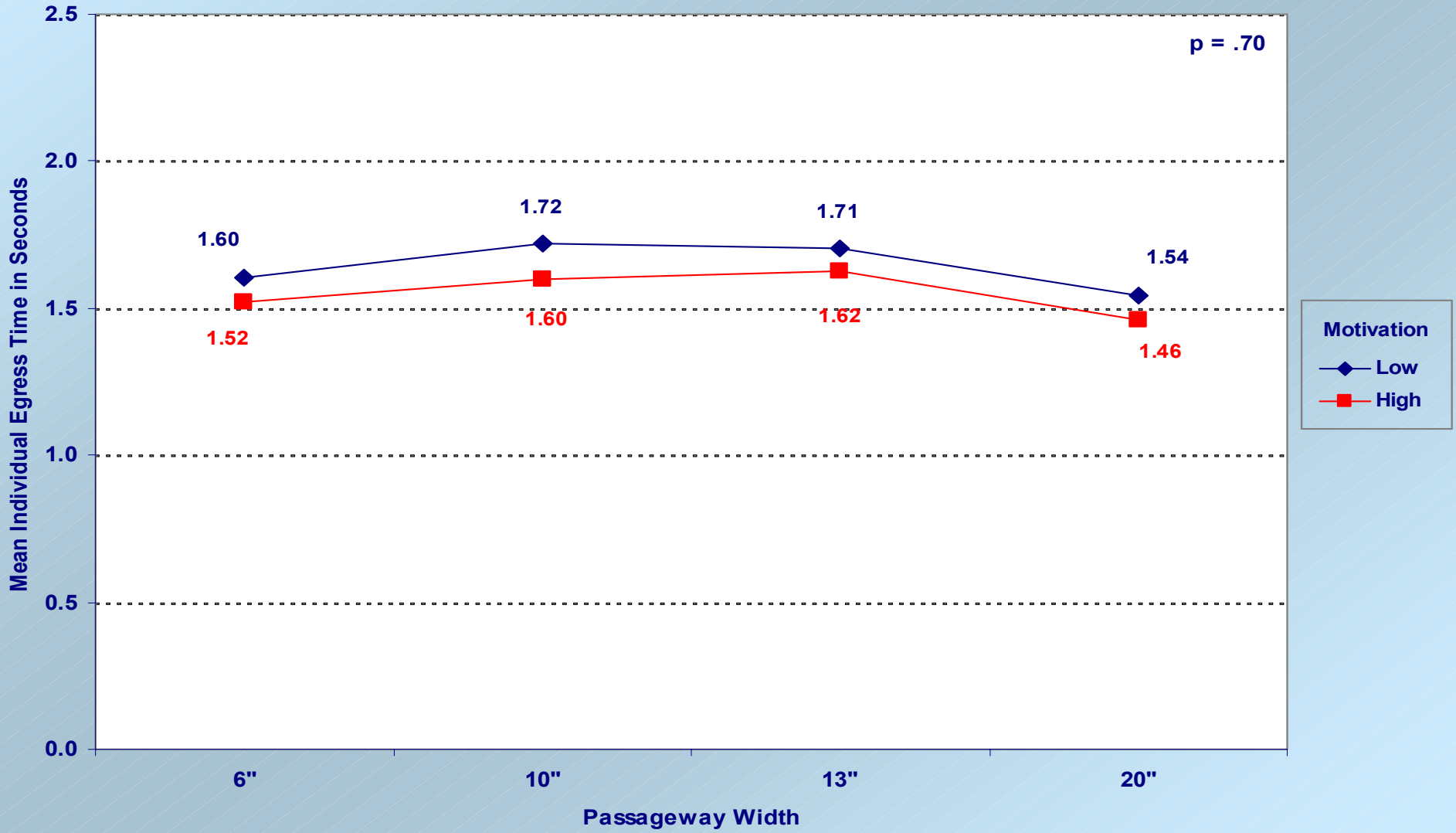
Design Factors Effects on Passenger Flow Rate


Passenger Flow Rate
Hatch Location Main Effect
2.5
2.0
1.5
1.0
0.5
0.0
p = .56
1.60
1.59
Mean Individual Egress Time in Seconds
In
Out
Hatch Disposal Location


Passenger Flow Rate
Group Motivation Main Effect
p = .001
2.5
2.0
1.5
1.0
0.5
0.0
Mean Individual Egress Time in Seconds
1.64
1.55
Low
High
Group Motivation


Passenger Flow Rate
Group Density Main Effect
p = .46
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
1.56
1.61
1.60
Low (30)
Medium (50)
High (70)
Group Density


Passenger Flow Rate
Passageway Width Main Effect
p < .001
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
1.56
1.66
1.66
1.50
6"
10"
13"
20"
Passageway Width


Passenger Flow Rate
Passageway Width X Motivation Interaction
p = .70
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
1.60
1.72
1.71
1.54
1.52
1.60
1.62
1.46
6"
10"
13"
20"
Passageway Width
Motivation
Low
High

Conclusions

- Effects on produced by differences in passageway configuration were small and often correlated with the human factors effects.
- Effects of hatch removal and disposal were generally small and resistant to interactions with passageway configuration.
- Effects produced by differences in subject motivation level were small and not qualitatively different from each other; there were no interactions between motivation level and the other design factors.
- Subject group density effects were small and not predictive of passenger flow rate.

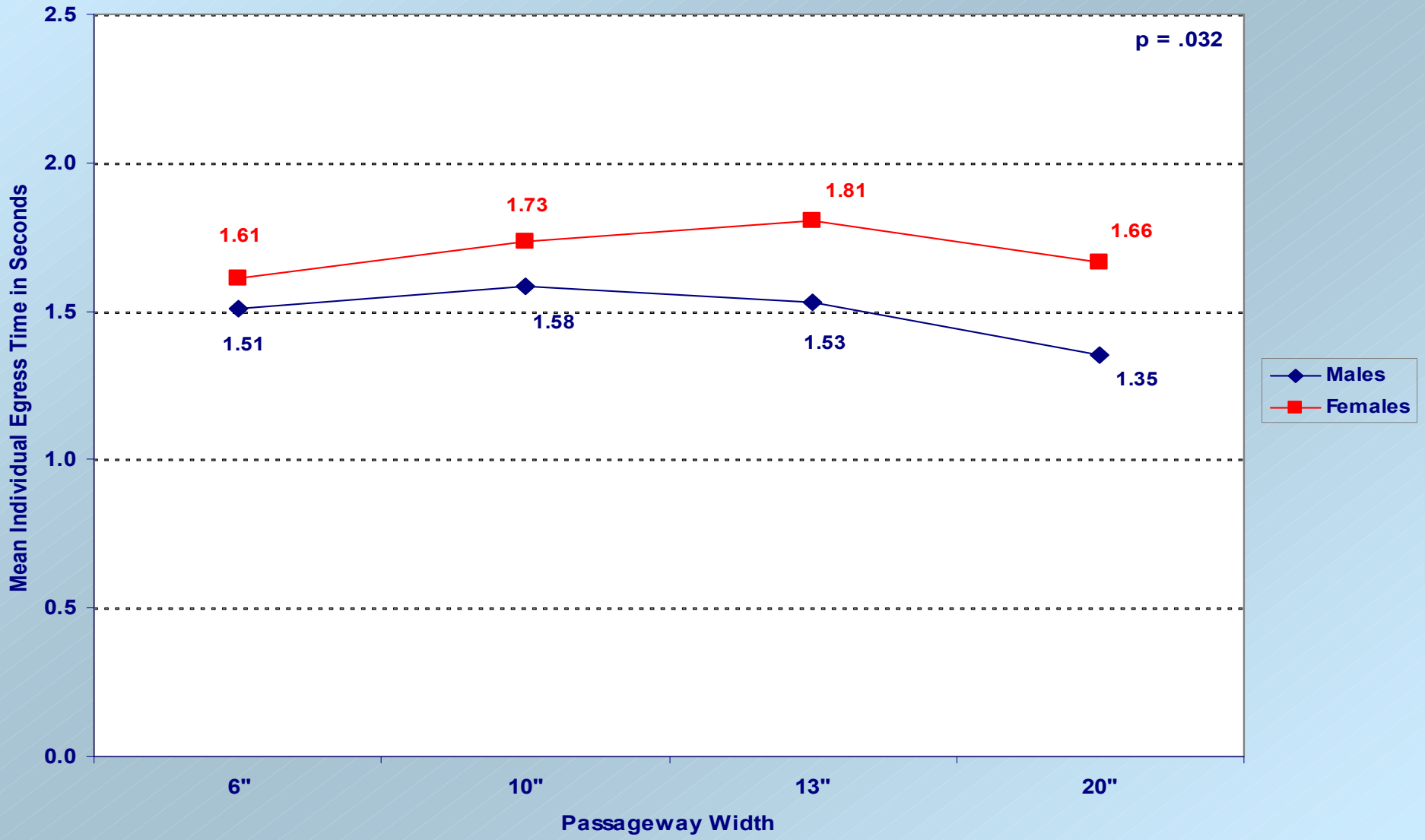
Evacuation Effects

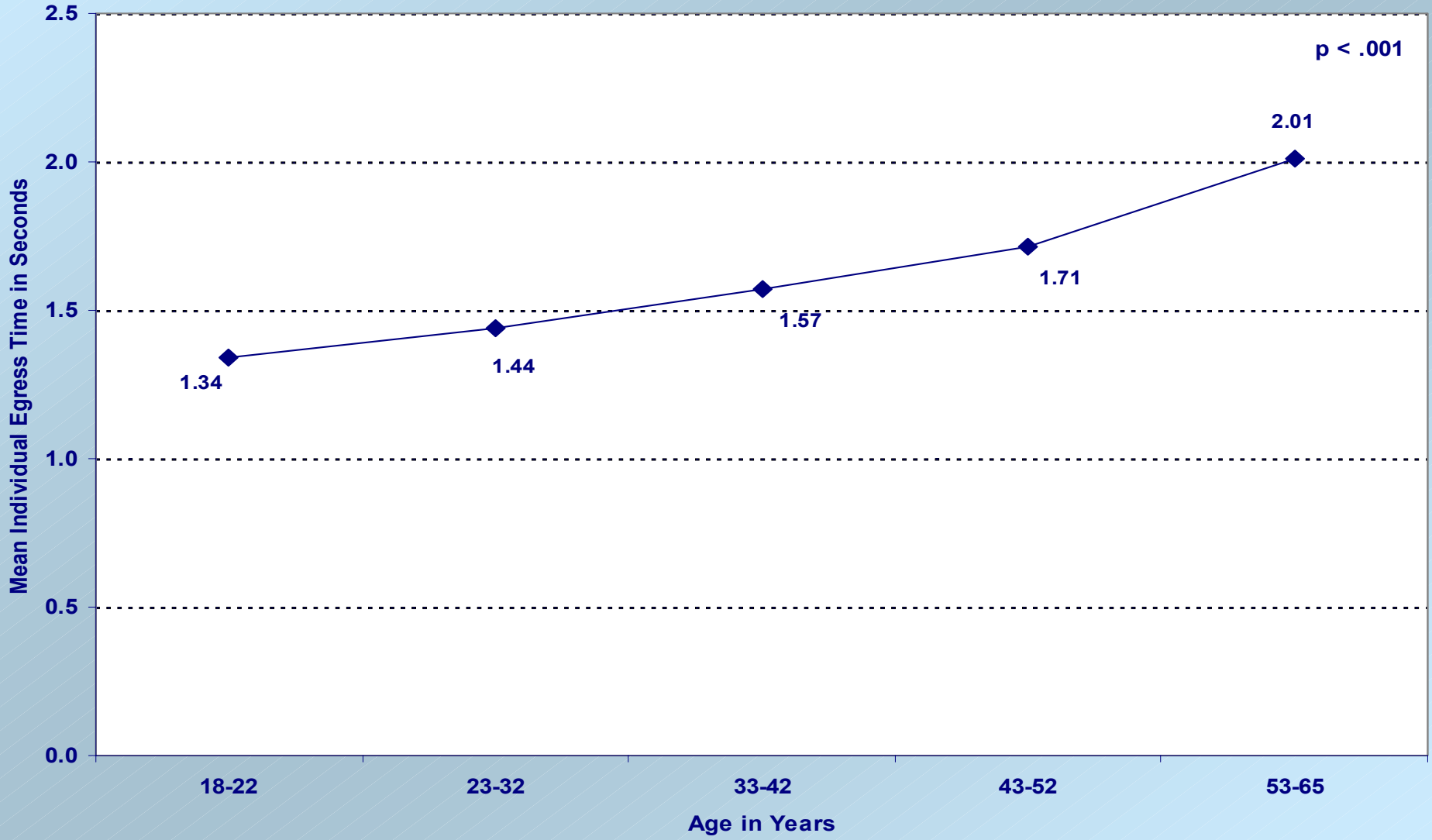
Human Factors Effects on Passenger Flow Rate

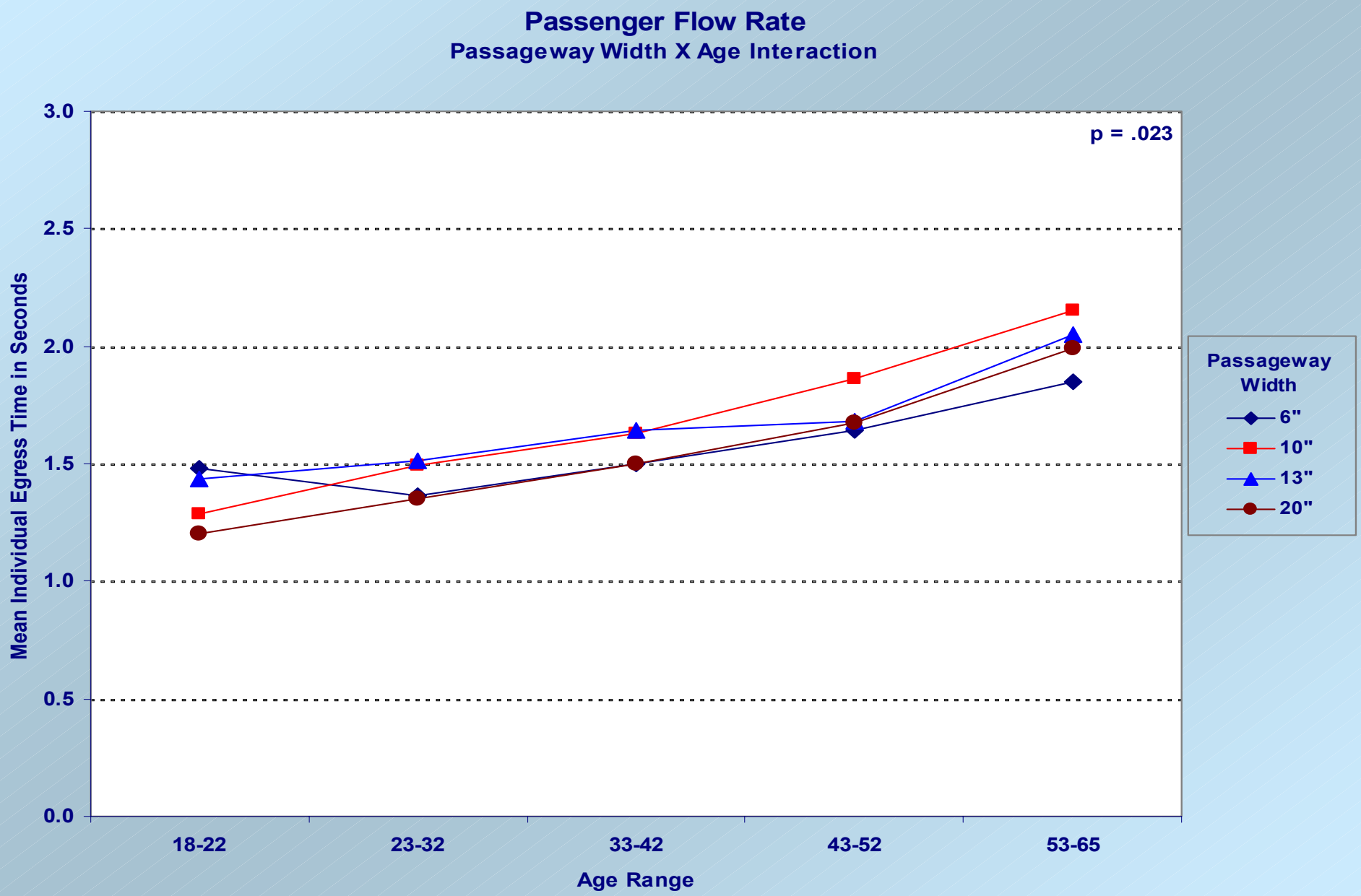

Passenger Flow Rate
Subject Gender Main Effect
p < .001
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
1.70
1.49
Male (n=1180)
Female (n=1129)
Gender

Passenger Flow Rate

Passageway Width X Gender Interaction

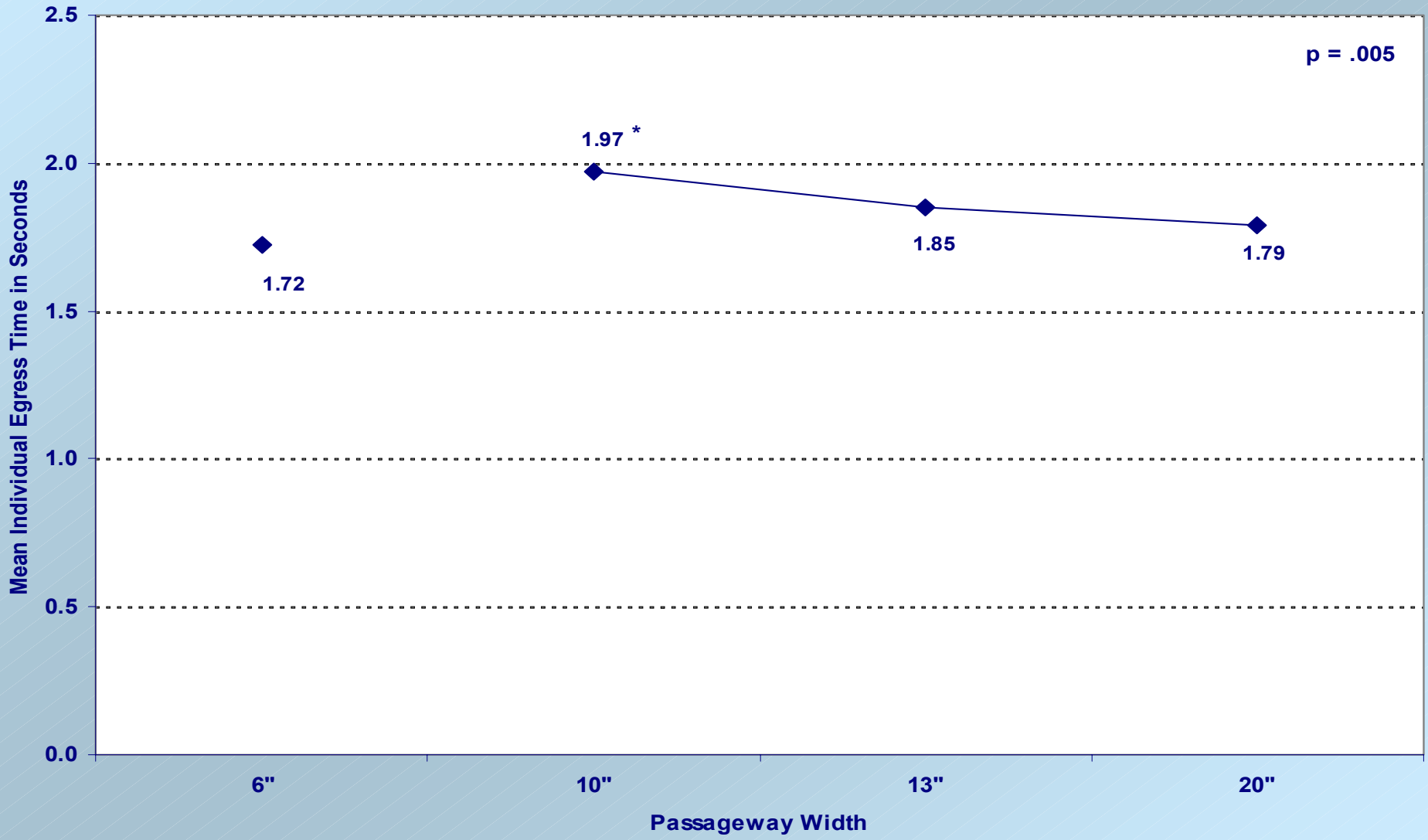


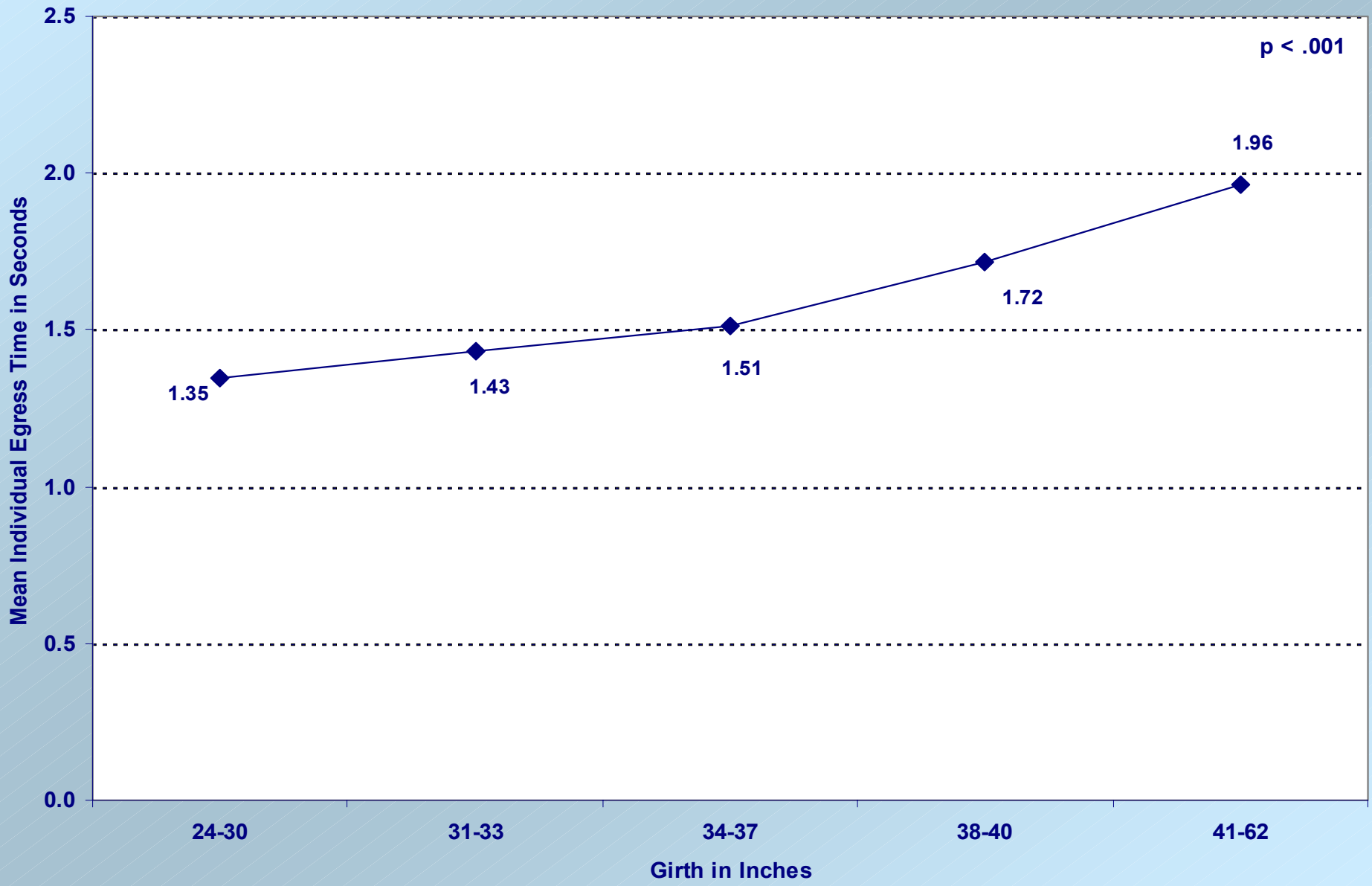

Passenger Flow Rate
Subject Age Main Effect
p < .001
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
1.34
1.44
1.57
1.71
2.01
18-22
23-32
33-42
43-52
53-65
Age in Years

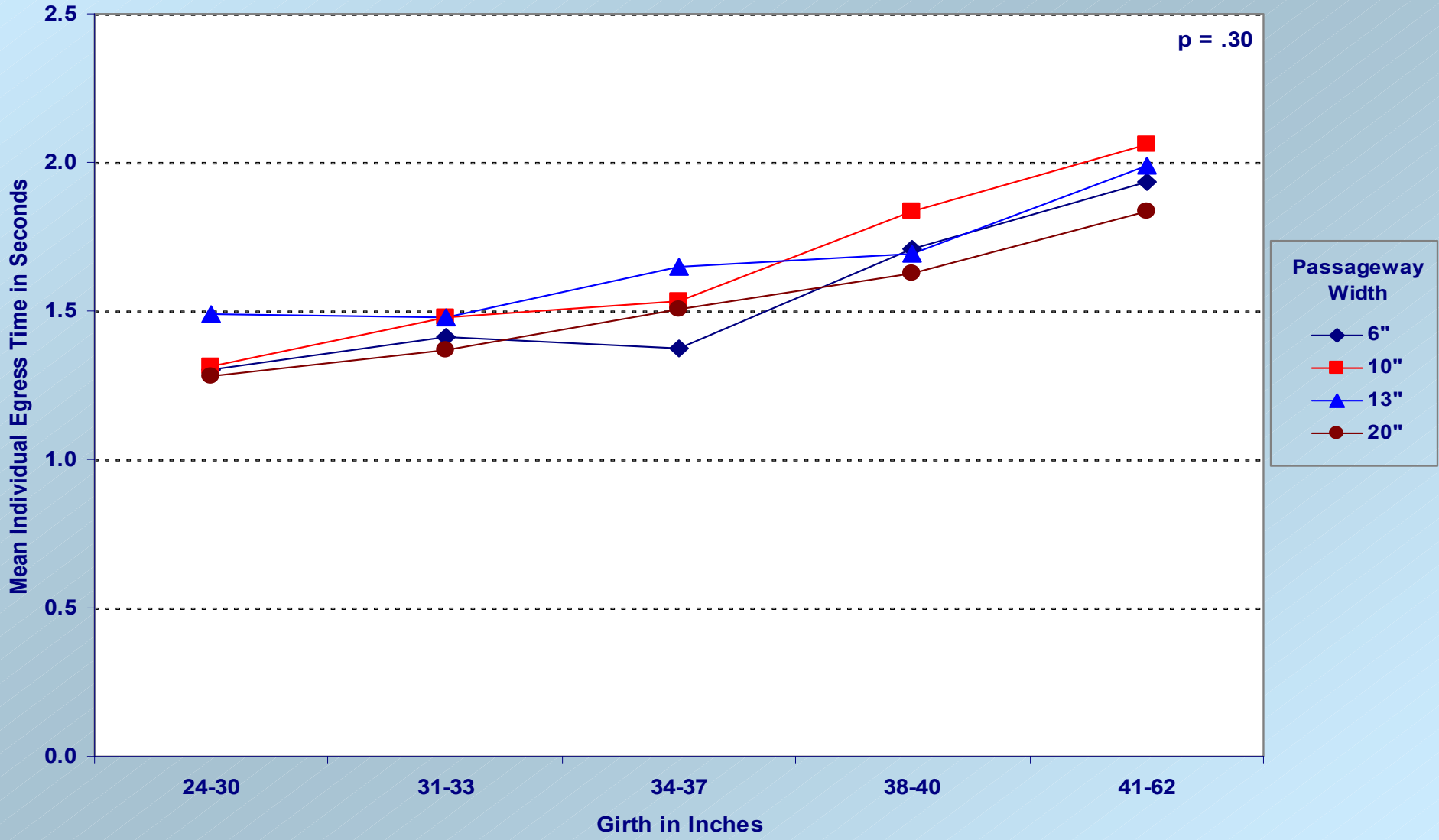

Passenger Flow Rate
Passageway Width X Age Interaction
p = .023
Mean Individual Egress Time in Seconds
3.0
2.5
2.0
1.5
1.0
0.5
0.0
18-22
23-32
33-42
43-52
53-65
Age Range
Passageway Width
6"
10"
13"
20"

Passenger Flow Rate

Passageway Width X Older Subject Simple Interaction

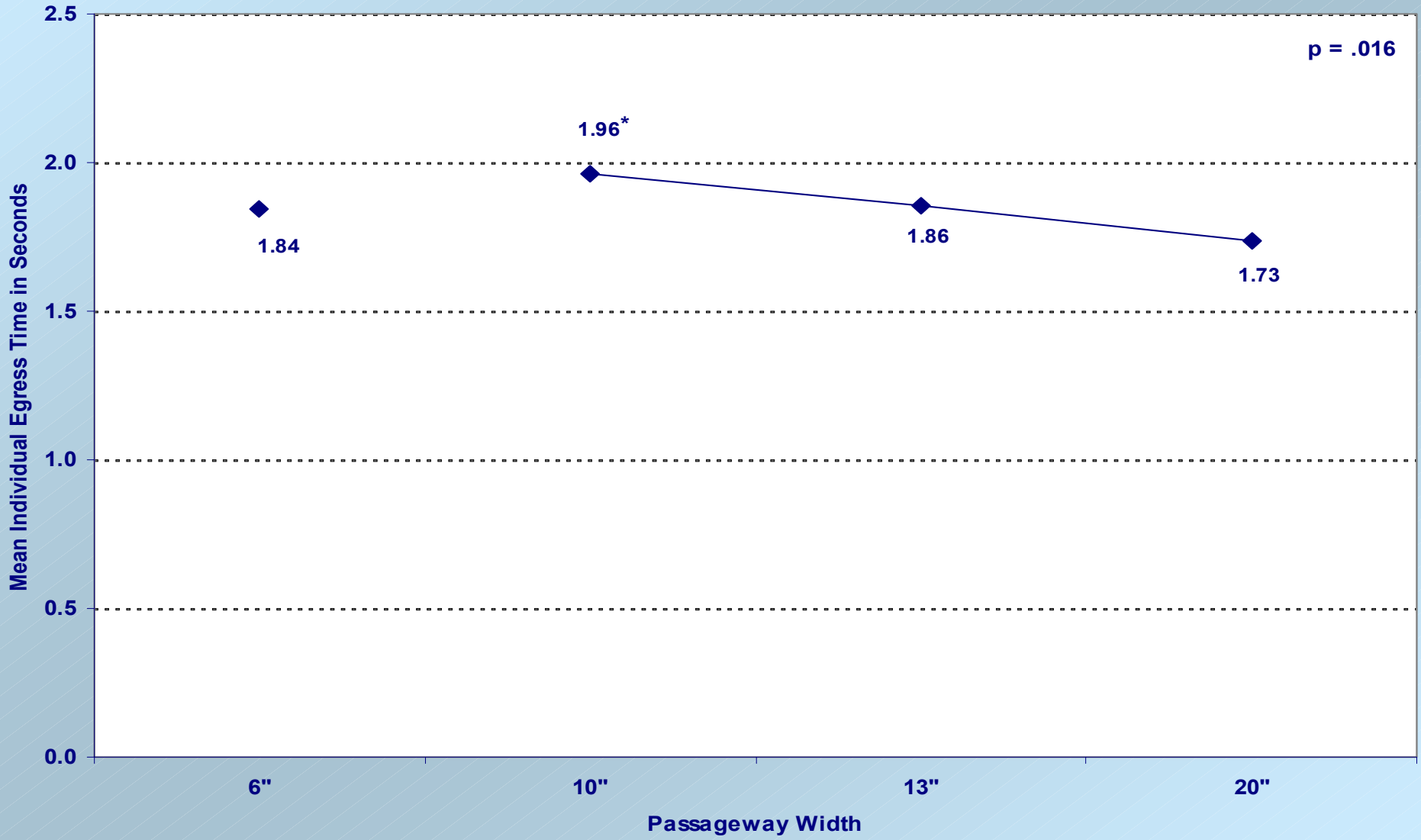


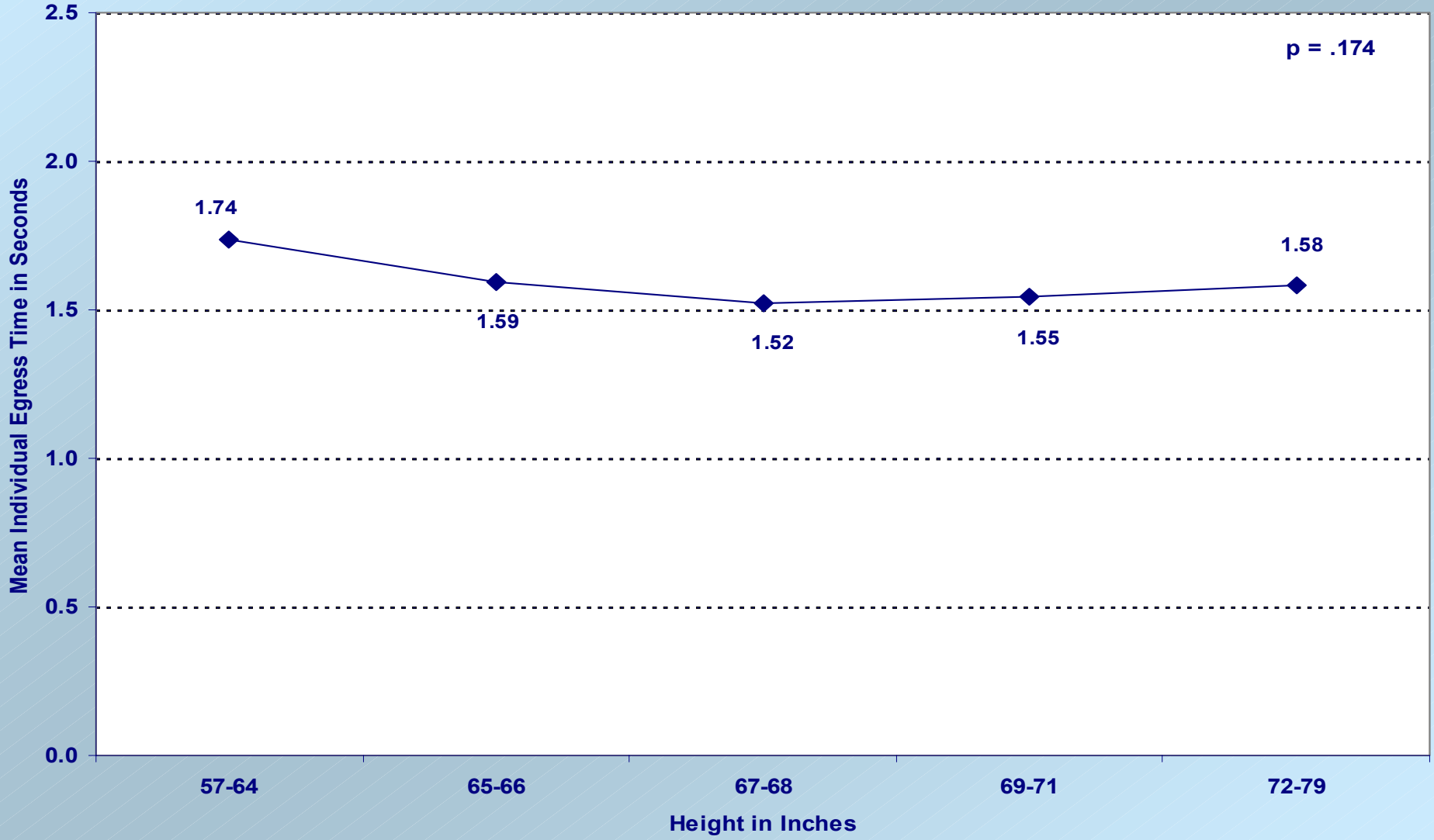

Passenger Flow Rate
Subject Girth Main Effect
p < .001
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
1.35
1.43
1.51
1.72
1.96
24-30
31-33
34-37
38-40
41-62
Girth in Inches

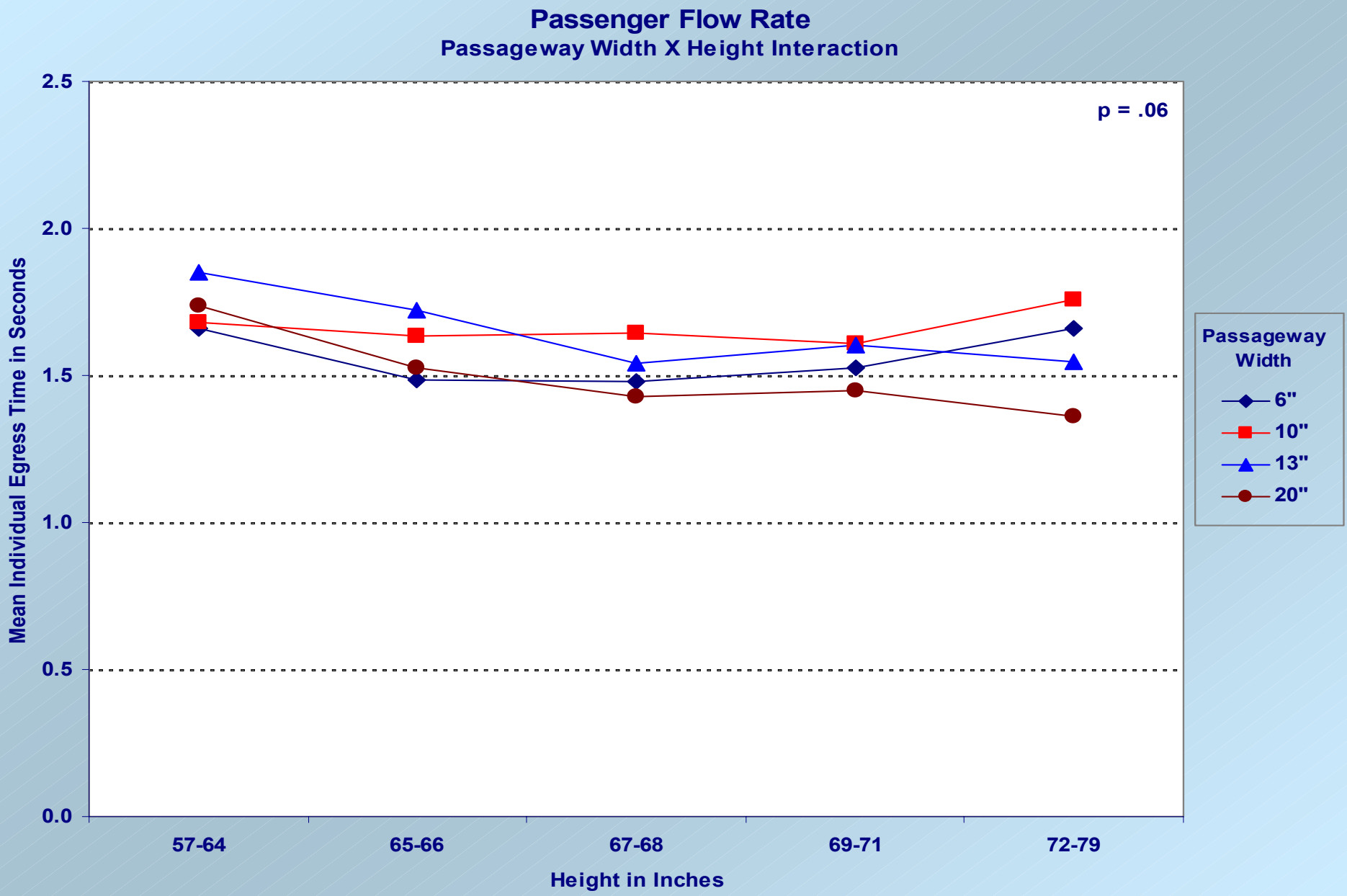

Passenger Flow Rate
Passageway Width X Girth Interaction
p = .30
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
24-30
31-33
34-37
38-40
41-62
Girth in Inches
Passageway Width
6"
10"
13"
20"

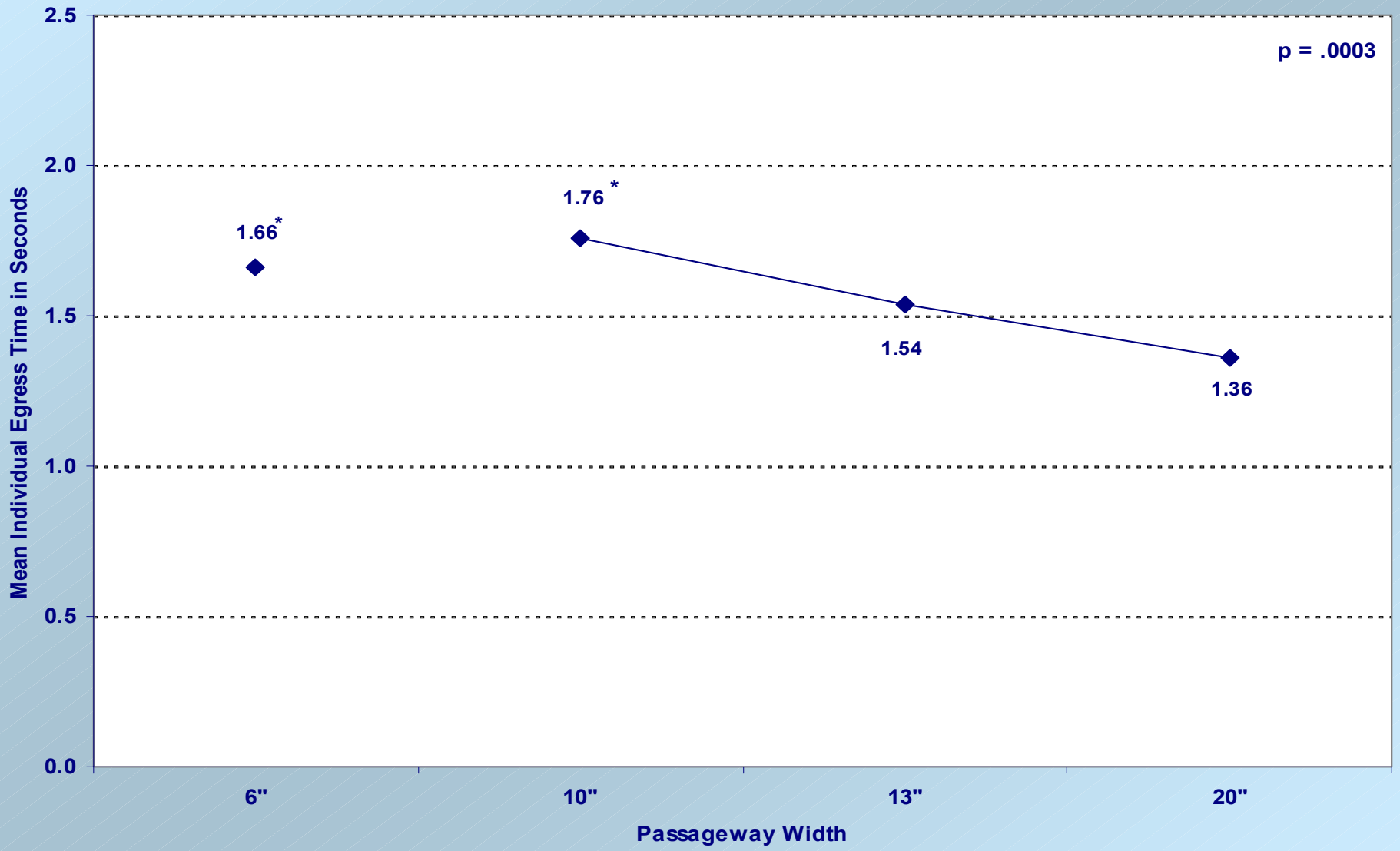
Passenger Flow Rate

Passageway Width X Larger Girth Simple Interaction



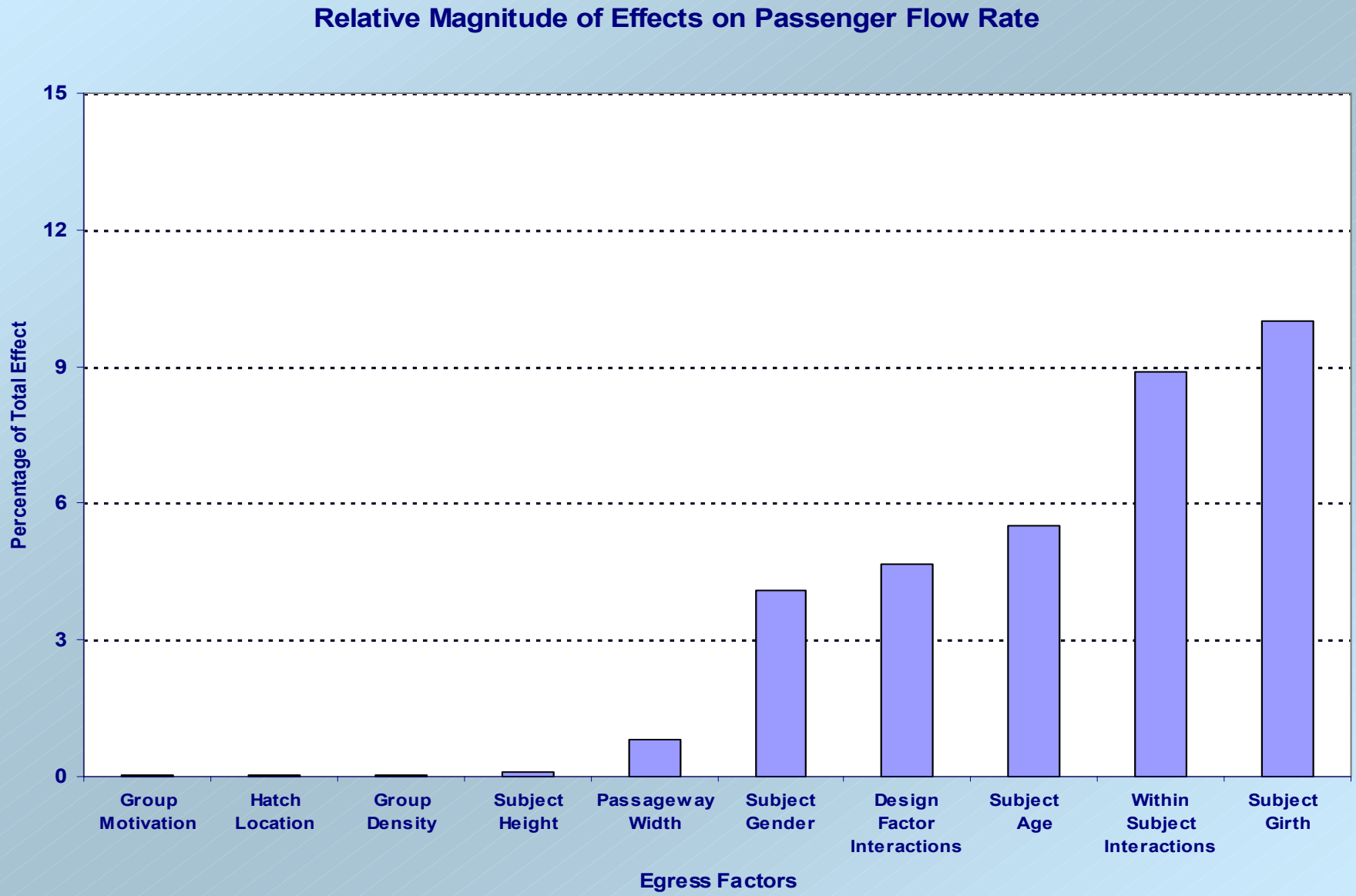

Passenger Flow Rate
Subject Height Main Effect
p = .174
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
1.74
1.59
1.52
1.55
1.58
57-64
65-66
67-68
69-71
72-79
Height in Inches


Passenger Flow Rate
Passageway Width X Height Interaction
p = .06
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
57-64
65-66
67-68
69-71
72-79
Height in Inches
Passageway Width
6"
10"
13"
20"


Passenger Flow Rate
Passageway Width X Taller Subject Simple Interaction
p = .0003
Mean Individual Egress Time in Seconds
2.5
2.0
1.5
1.0
0.5
0.0
1.66*
1.76*
1.54
1.36
6"
10"
13"
20"
Passageway Width

Conclusions

- Human factors effects accounted for most of the variance in the passenger flow rate data.
- Age, girth, and gender were predictive of passenger flow rate results, as older and larger subjects, particularly females, were found to egress more slowly.
- These findings replicate and extend those from previous evacuation research with more practiced subjects.


Relative Magnitude of Effects on Passenger Flow Rate
Percentage of Total Effect
15
12
9
6
3
0
Group Motivation
Hatch Location
Group Density
Subject Height
Passageway Width
Subject Gender
Design Factor Interactions
Subject Age
Within Subject Interactions
Subject Girth
Egress Factors

It’s the people...